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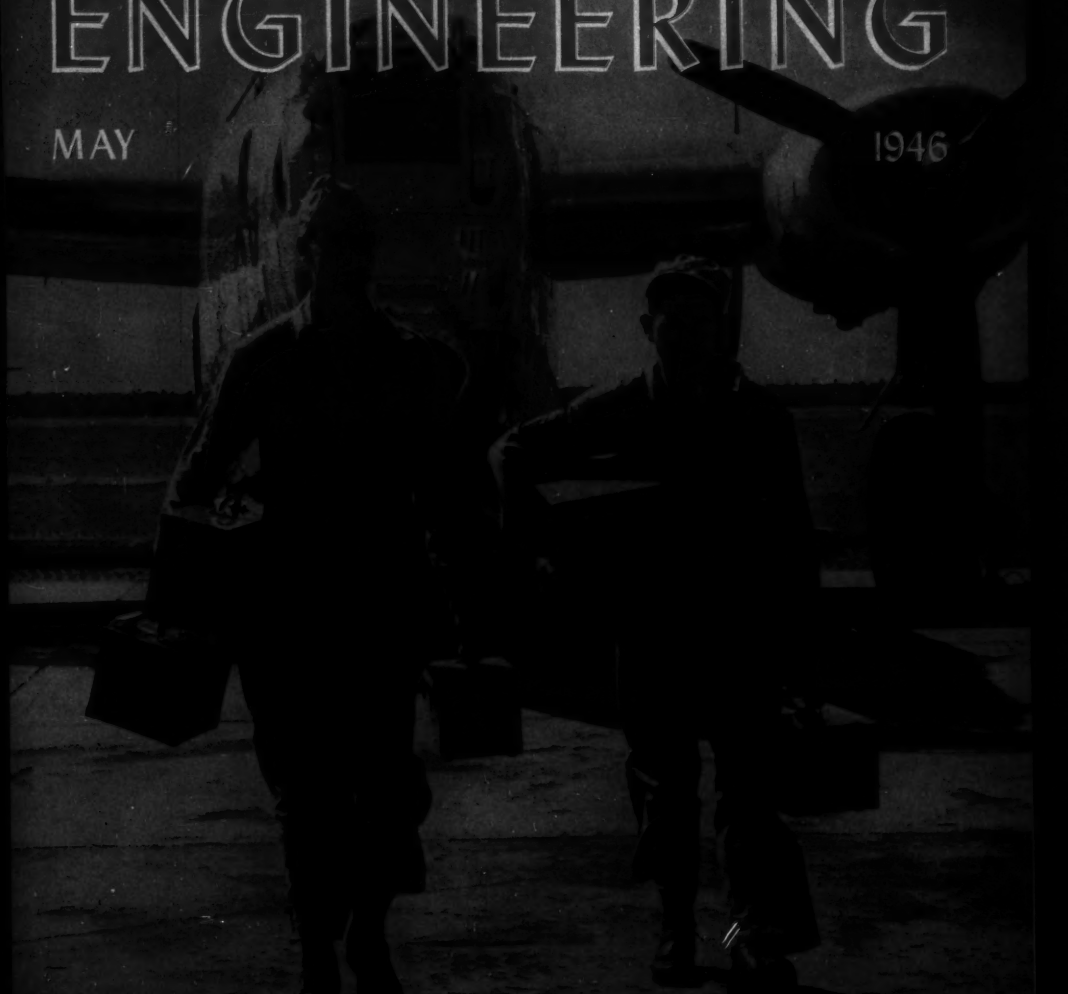
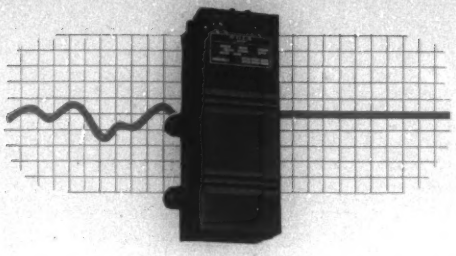
# ELECTRICAL ENGINEERING

MAY 1946



AIEE SUMMER CONVENTION, DETROIT, MICH., JUNE 24-28, 1946



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Are you looking for new ways to—

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# ELECTRICAL ENGINEERING

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MAY
1946

**The Cover.** Portable units used by the United States Army Air Forces for testing air-borne radar sets. The use of microwave testing equipment is described in a paper in the *Transactions* section of this issue (*pages 274–90*).

Photo courtesy Radiation Laboratory, Massachusetts Institute of Technology

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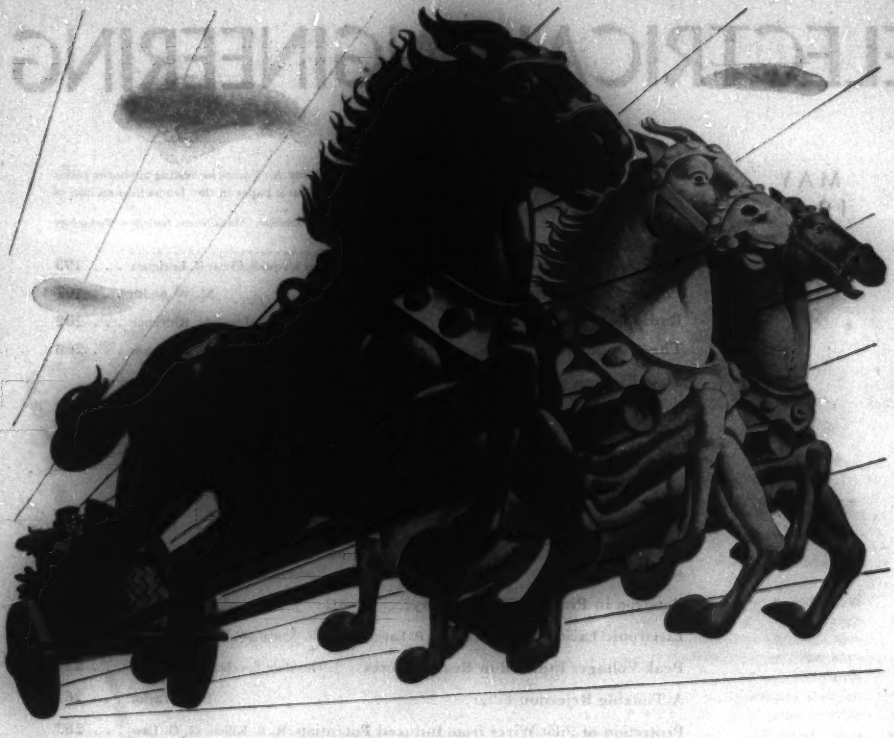

## Where There is Horsepower . . .

# THERE IS WIRE

Coal . . . Water . . . Oil . . . these are our sources of power. Our early use of each of them was crude and localized and wasteful—before the time of electrical wire.

Now, wire harnesses horsepower. Wire traps it at its birth—even bringing about its generation. Wire packages power and brings it into our homes. Wire transforms power into a thousand different characters. Wire focuses—diffuses—interrupts—intensifies—splits—graduates power; transmuting one energy to many other forms: to heat—to light—to sound—or back again to whirling motion. Wire guides and controls power and makes it universally useful.

The use of horsepower is a many-sided science, now that wire is here. Each specialized application has its specialized wire counterpart. The development of these wires is in itself a scientific undertaking . . . a challenge . . . an achievement . . . a source of pride for the wiremakers among whom a pioneering leader is Belden Manufacturing Company.

**Belden**

WIREMAKER FOR INDUSTRY

# HIGHLIGHTS.....

**Summer Convention.** Advance plans for the summer convention to be held in Detroit have expanded to prewar dimensions. Electronics and instruments and measurements have been given special importance in the program. Details of the four scheduled trips of a technical nature, the social events for men and women, the three golf tournaments, and the very necessary hotel accommodations already have been completed (*pages 214–16*).

**Postwar Uses for War-Born Products.** Many products which did valiant service for the Armed Forces during the war are now in a state of conversion to industrial form. The gyroscopic stabilizer, the absolute altimeter, and nuclear energy, among others, probably will be utilized to advantage in the postwar era (*pages 208–13*). One of the most important scientific developments to come out of the war, radar, contributed much to Allied superiority both in offensive and defensive warfare. In peacetime, radar can go far toward providing safety of navigation and traffic control on commercial air and sea lanes (*pages 202–07, Transactions pages 307–13*). One design suitable for peactime application of radar is the "electronic navigator" (*Transactions pages 271–3*). For the testing of microwave radar, in general the same instruments and techniques are used as those involved in the testing of microwave radio communication systems (*Transactions pages 274–90*).

**Mexican Electrification.** The progress of Mexican electrification, which in the past had been slow due to the country's widely distributed agricultural population and extreme concentration of industry, was impeded further by wartime restrictions. The Mexican Government, in co-operation with privately owned public service companies, has taken stock of Mexico's electrical requirements and available power and on that basis has formulated a program to provide for the probable increase in demand during the next four years. Part I of a two-part article on the subject, prepared by members of the Mexico Section, appears in this issue (*pages 193–7*).

**The Amplidyne.** The amplidyne can be used as a voltage regulator, a speed regulator, or a current regulator, and can be applied to the control of a-c as well as d-c machines. Its high amplification powers and speed of response enhance its versatility (*pages 208–13*).

**Engineering Organization.** A conference at San Antonio, Tex., during the recent District meeting there, indicated a preponderance of opinion favoring "Plan B" of the planning and co-ordination committee's progress report (*EE, Apr '46, pp 169–73*) looking toward collaboration with the National Society of Professional Engineers on so-called "professional" matters and toward increased activity within the Institute on technical matters (*pages 217–18*).

**Standards.** A summary is given of a "Proposed Standards for Pool-Cathode Mercury-Arc Power Converters," which has been prepared as a revision of the 1934 AIEE "Report on Standards for Acceptance Tests for Metal-Tank Mercury-Arc Rectifiers" (*pages 224–5*). A comprehensive review of the revised "American Standard for Automatic Station Control, Supervisory, and Telemetering Equipment," also appears in this issue (*pages 223–4*).

**Research Legislation.** The McMahon Bill (atomic energy) and the Kilgore–Magnuson bills remain in the news. The presidents of four engineering societies have telegraphed their approval of the inclusion of a division of engineering among the civilian advisers in the McMahon control scheme (*page 235*), and the second bill has provoked an adverse statement of policy from the National Association of Manufacturers (*pages 235–6*).

**Arcing Ground Tests.** Contrary to current theory that arcing grounds of the restriking type can cause voltages to ground on an ungrounded system of the order of 6 to 8 times normal, investigation has proved that these voltages under ordinary circumstances are not likely to be greater than 2 to 3 times normal. One thus may conclude that deteriorated bus insulation rather than very high voltages is responsible for multiple insulation failures (*Transactions pages 298–306*).

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**Pilot Wires.** A method of protection has been devised for pilot wire systems which provides reliable and satisfactory operation of a-c pilot channels through low-voltage telephone-type cable, even though induced potentials high enough to operate discharge gaps may be present. This new method obviates the necessity of heavy over-insulation for protection in cases where conventional methods are not suitable (*Transactions pages 267–70*).

**Rejection Filter.** A new device which will remove leak and stray pilot frequencies from carrier telegraph systems with little disturbance to other parts of the system employs a Wheatstone bridge circuit whose capacitor elements may be adjusted to reject any frequency in a range of two to one. Two sections in tandem are used to secure a greater width of rejection band (*Transactions pages 263–7*).

**The Betatron in Industry.** Under supervision of the Office of Scientific Research and Development, the betatron was developed from a physics laboratory apparatus to an industrial radiographic machine. Betatrons having a maximum energy of 20,000,000 electron volts have proved their value to industry by detecting small flaws in as much as 20 inches of steel or other heavy metal (*Transactions pages 241–*).

**Model Law.** With the recent action of the AIEE board of directors officially recognizing the "Model Law for the Registration of Engineers", the subject is of renewed importance to Institute members. Full text of the latest (1945) revised edition is reprinted here *pages (219–21)*.

**Letters to the Editor.** Walther Richter (F '42) and K. L. Hansen (F '34) continue a friendly dispute over "the concept of generating a voltage by the cutting of magnetic lines" versus "the concept of having the voltage generated by a change of flux associated with a loop" (*pages 242–4*). C. M. Jansky (F '32) reminds readers of *Electrical Engineering* that the recent radar-to-the-moon tests made by the Signal Corps were not the first demonstrations of atmospheric penetration by electromagnetic waves (*page 244*).

**Miscellany.** Numerous reports have appeared in the press outside the United States of revived activity in the electrification of railroads (*page 237*) and in hydroelectric undertakings (*page 236*). Research Corporation, New York, names the projects and institutions it will aid for the coming year (*pages 238–9*). Announcement of an award for engineering educators raises the question of what standards will guide the choice of a recipient (*page 242*). Reconversion reaches the Big Inchpipe line, as application is made to use it for transporting natural gas instead of oil (*page 240*).


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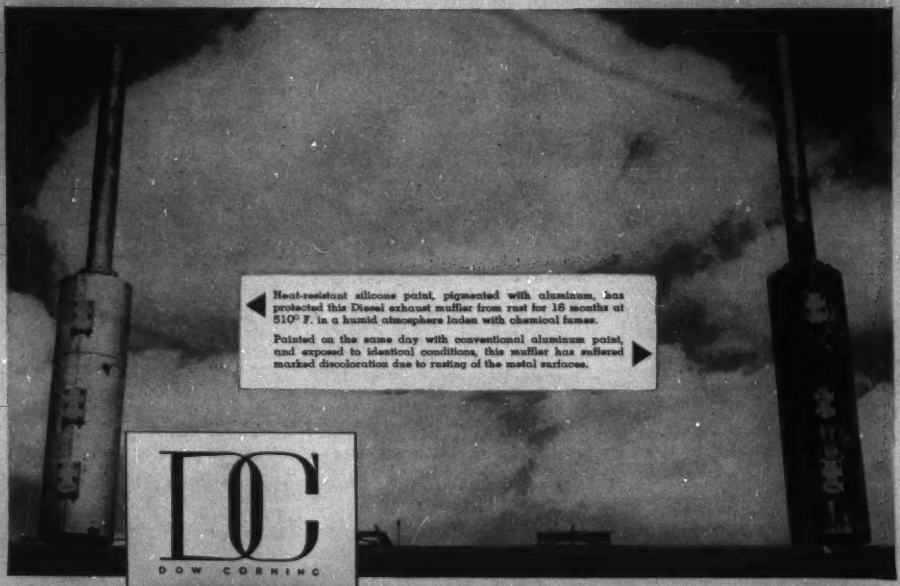
# DC SILICONE RESINS

## For paint that protects at 500° F.


Heat-resistant silicone paint, pigmented with aluminum, has protected this Diesel exhaust muffler from rust for 16 months at 510° F. in a humid atmosphere laden with chemical fumes.
Painted on the same day with conventional aluminum paint, and exposed to identical conditions, this muffler has suffered marked discoloration due to rusting of the metal surfaces.
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### . . . Proof Against Moisture, Weathering, and Chemical Fumes

Now—with these *unique* silicone resins—you can readily formulate heat-resistant paints that fill the gap between organic paints and ceramic coatings. Available today, DC 801, 802, and 803 can be blended for practically every degree of hardness and flexibility. Though markedly different from all previous paint vehicles, these silicone resins can be formulated and mixed—like other paint resins—with inorganic pigments. DC 801, 802, and 803 are largely inorganic. That's why they resist heat, oxidation, ultra-violet rays, and chemical fumes. In addition, they are waterproof, water-repellent and non-yellowing. For further information, call on Dow Corning.

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Developed through Okonite Research . . .

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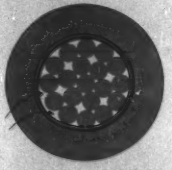
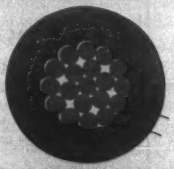
(Conductors Shown in Color)



**AIR POCKETS EXCLUDED FROM DIELECTRIC FIELD**

WITH SEMICON

1 Uniform stress conditions result from smooth, cylindrical conducting surface
2 No voids develop because Semicon tape and insulation are vulcanized together
3 No internal corona cutting can occur since the voids which cause it are eliminated



**AIR POCKETS IN DIELECTRIC FIELD**

WITHOUT SEMICON

1 Points of high stress exist because of irregular conductor surface
2 Voids, gaps or "pockets" can develop because cable movements may distort insulation
3 Voids under stress result in ionization (internal corona cutting)

Longer cable life through greater built-in protection — that's what users of high voltage cables are assured by the Semicon tape now an integral part of every rubber insulated cable made by Okonite for operation at voltages above 2000 between phases.

Semicon tape is a strong cotton fabric impregnated and coated on both sides with a semi-conducting neoprene compound developed in the Okonite laboratories. It is applied between the Okoloy-coated conductor and the rubber insulation, being wrapped helically around the conductor with sufficient lap to insure complete coverage. It is bonded to the inner surface of the insulation during vulcanization so that no voids or spaces are present in which corona cutting of the inner surface of the insulation might start.

Comparative cross-section views at left show at a glance the advantages of Semicon tape . . . the absence of voids or air pockets next to the insulation at the conductor surface where the electrical stress is high.

Even under the most severe test conditions, no failure caused by internal corona cutting has ever developed in a cable made with Semicon tape, first used in Okonite-engineered cable in 1938. Furthermore, Semicon tape has considerably raised voltage test values. As a result, factory a-c high voltage tests have been increased by 25 percent, a standard Okonite precaution that provides additional insurance against the possibility of insulation defects.

For further information on Semicon tape and the high voltage cables in which it is used, get in touch with Okonite engineers. The Okonite Company, Passaic, N. J.

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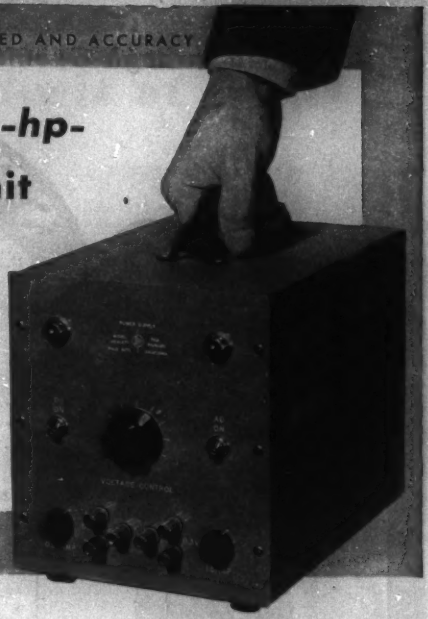

New -hp- Model 710A

With good regulation, light weight and small physical size, the new -*hp*- Model 710A Power Supply is now available at the exceptionally low price of $75.00. Every laboratory and production department will find hundreds of uses for this versatile power source. The low cost makes it practical and economical to utilize several of them.

**RANGE 180—360 VOLTS**

The -*hp*- Model 710A Power Supply will deliver any required voltage between 180 and 360 volts, with less than 1% variation for output currents of from 0 to 75 ma. (Maximum current is 100 ma).

Line voltage variations of ± 10% cause less than 1% change in output voltage.

Since total noise and hum output is less than .005 volts for any condition of operation, the -*hp*- Model 710A may be used to supply low-level, high-gain amplifier stages without the necessity of additional filtering.

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Either positive or negative terminal may be grounded

Small size, consumes a minimum of bench space

Holds DC voltage constant from 0 to 75 ma load

Holds DC voltage constant with ± 10% change in line voltage

Low AC ripple output

Low cost . . . $75.00

1198

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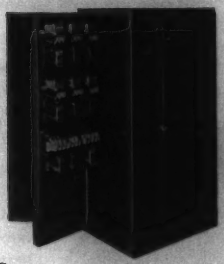

*Safront* panel swung out to show timing and sequencing relays. Adjusting dials are on front of this panel for maximum safety. Separable connector strip allows easy removal of panel for installation or maintenance.

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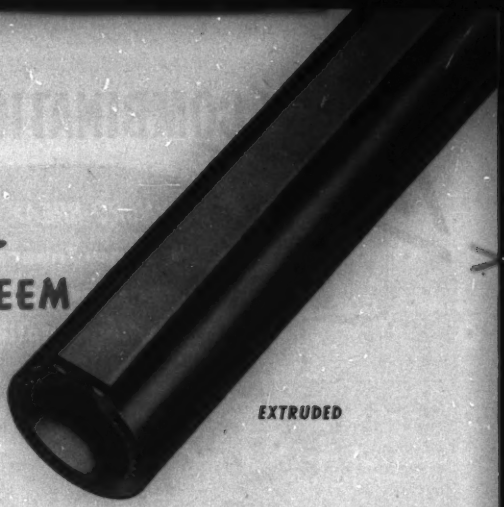

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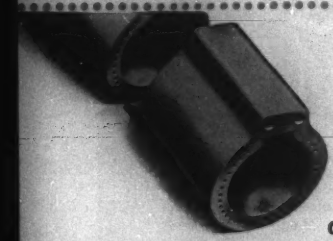

CUT

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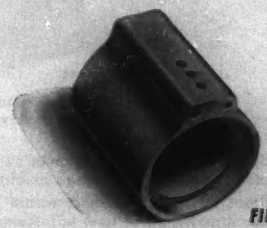
4



FIRED

SOME intricate ceramic designs machined from steatite seem unbelievably complicated. Actually they are simpler than they seem. By incorporating complex design details in extruded, pressed or cast basic shapes, American Lava Corporation frequently has been able to minimize the relatively slow and costly machining process. Production study may show desirable design alternatives which permit faster deliveries, lower cost.

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*Second Award February 13, 1943*
*Third Award September 28, 1943*
*Fourth Award May 27, 1944*
*Fifth Award December 2, 1944*

AMERICAN LAVA CORPORATION

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83RD YEAR OF CERAMIC LEADERSHIP

# Mexico's Electrification Program— I

BASIL NIKIFOROFF
MEMBER AIEE

ALFONSO FERNANDEZ DEL BUSTO
ASSOCIATE AIEE

ALEJANDRO PAEZ URQUIDI
ASSOCIATE AIEE

OSCAR R. ENRIQUEZ
ASSOCIATE AIEE

THE PURPOSE of this article is to acquaint the reader with the present status of electrification in the Mexican Republic. It may appear that the results already obtained and the plans proposed for electrification are very modest, when compared with accomplishments and results achieved in the United States, but they are of vital importance to the economy and welfare of Mexico.

**This first part of a two-part article presents a general picture of what has been accomplished thus far in Mexico's effort to solve its power problem as the first step toward industrialization. Part I concentrates on the present status of the Mexican electrical industry and the reasons for its belated development. It includes a discussion of plans for the future which call for an increase during the next four years of 53 per cent over the capacity of existing installations.**

The development of the electrical industry in Mexico in the past has been very slow. This is explained by many causes. The principal reason which, during the past year, prevented the electrical as well as the industrial development of the country, was the restricted possibility of obtaining machinery and equipment required for increasing the productivity of the industries as well as for increasing the capacity of the electrical plants and of the transmission and distribution systems. This resulted in a general slowdown of such developments during the years of emergency, in spite of the country's requirements.

With the end of the war and better prospects for obtaining machinery and equipment, a large number of Mexican industries are anxious to obtain additional power for enlarging their existing works as well as for establishing new factories. Taking as a basis the immediate requirements of various industries for additional power as well as the most pressing needs of the rest of the population, the figures given in this article should be considered as a minimum of work to be accomplished during the next three to four years.

For a better illustration of present conditions and of the problem ahead, a number of figures are presented which give a comparison of statistical data in the United States and Mexico pertaining to the electrical industry. It is hoped that familiarity with these data will inspire an appreciation of the work which must be accomplished and the difficulties which must be overcome under the existing economic possibilities in order for the great mass of population to receive the benefits of electricity.

## THE PROBLEM OF ELECTRIFICATION AS AFFECTED BY THE CHARACTERISTICS OF THE COUNTRY

In order to explain the reason for the actual state of the electrical industry in Mexico, as well as its most pressing requirements, it is necessary to outline briefly the main characteristics of the country which affeet the electrification problem.

Mexico occupies an area of 758,259 square miles. Its population, according to the 1940 census, is 19,654,000, an average of 26 people per square mile while the average population per square mile in the United States is 44 persons. The density of population in Mexico is not only very low but also the major portion of the population lives outside of the large centers and in small townships with less than 1,500 people per town (see Table I).

**Table I. Distribution of Population in Mexico**

| Size of Cities (Number of Inhabitants) | Accumulated Sums | | Percentage of Total Population | Corresponding Percentage in the United States |
|---|---|---|---|---|
| | Number of Cities | Population | | |
| More than 100,000 | 4 | 2,001,581 | 10.2 | 28.8 |
| More than 50,000 | 13 | 2,652,970 | 13.5 | 34.4 |
| More than 20,000 | 43 | 3,551,094 | 18.1 | |
| More than 10,000 | 97 | 4,296,265 | 21.8 | 47.6 |
| More than 5,000 | 262 | 5,397,544 | 27.5 | 52.7 |
| More than 2,000 | 966 | 7,469,227 | 38.0 | |
| More than 1,500 | 1,491 | 8,369,075 | 42.6 | |
| Total number of localities | | 114,945 | | |

As Table I shows, more than 50 per cent of the population in the United States is concentrated in

Essential substance of a paper presented by the Mexico Section at the AIEE South West District meeting, San Antonio, Tex., April 16–18, 1946. Paper was prepared under direction of Basil Nikiforoff.

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cities of 5,000 or more inhabitants while in Mexico this figure is only 27.5 per cent. Even including the centers of population with only 1,500 inhabitants or more this figure will be only 42.6 per cent.

The situation is reversed in a comparison of the distribution of industries throughout Mexico. These are concentrated largely in a few states. Estimating the concentration of industries on the basis of the value of their production will give the following results:

| | |
|---|---|
| Federal District | 31.4 per cent |
| Nuevo León | 11.8 per cent |
| Puebla | 10.4 per cent |
| Veracruz | 9.8 per cent |
| 28 remaining states | 36.6 per cent |

Actually the concentration of industries is even greater as they are not distributed throughout the few states mentioned but are concentrated in one or two zones of each state.

As a result of such industrial concentration, electrical service systems have been developed mainly to supply the industries or, in a few cases, agricultural centers, omitting large extensions for scarcely populated parts of the country where there is little demand for energy.

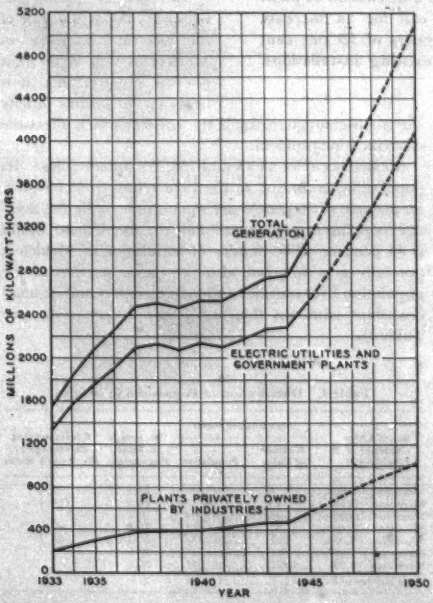


**Figure 1. Representation of total annual power generation in Mexico since 1933, including probable generation for the years 1946–50**

The difficulty of supplying power economically from large electrical systems to scarcely populated regions, with people having small purchasing power and a low standard of living, has been overcome partly by the installation of a large number of small isolated plants supplying individual localities, but even this solution provides electrical service for only 1,206 townships out of a total number of 114,945 localities. Therefore, counting the centers of population with less than 1,500 inhabitants only, approximately 1.1 per cent of such localities have electrical service at present. In the country as a whole approximately 4,000,000 people, or only 20 per cent of the total population, use electricity, leaving approximately 16,000,000 people without this facility. The lack of electrical supply throughout the country is also the reason why new industries are being located close to the already existing industrial centers in preference to location in the country near the source of supply of raw materials, thus aggravating the situation.

Mexico's electrification problem has two principal aspects:

1. To have available sufficient generating capacity for satisfying the needs of the population and industries and permitting their unhampered development instead of limiting the use of electricity, as at present, to the amount of energy available.

2. To promote and develop new industrial and agricultural centers, providing them with an abundant supply of power from new generating plants to be created for that purpose and from transmission and distribution networks of the existing power systems.

## PRESENT STATUS OF THE MEXICAN ELECTRICAL INDUSTRY

A total of 1,266 generating plants were in operation at the end of 1945 with a total capacity of 756,000 kw, and a yearly production of 3,068,000,000 kilowatt-hours. While the average capacity of all of these plants is only 600 kw, the capacity of the largest hydroelectric station at Necaxa reaches 100,000 kw. Of the total number of plants, 623 belong to public service utilities, the balance being industrial plants, although some of these sell part of their production to the public. Approximately 58 per cent of all of the plants use hydraulic energy. The rest are divided equally between thermoelectric and internal combustion type. Approximately 56 per cent of the total capacity is generated at a frequency of 60 cycles, 42 per cent at 50 cycles, and the remaining 2 per cent at 42 and 25 cycles or direct current.

From the foregoing figures it can be seen that the installed generating capacity per capita equals 38 watts with an annual consumption of 156 kilowatt-hours, or 1/10 and 1/11 respectively of the figures corresponding to the installed capacity and consumption per capita in the United States. The curves in Figure 1 indicate the total annual generation of the country for the years 1933 to 1945 as well as the probable annual production of electric energy from 1946 to 1950. The curve per-

mits analysis of the conditions under which the development of the electrical industry took place during the last 12 years.

Between the years of 1933 and 1937 the average annual growth of production was 12.8 per cent, varying from 8.8 per cent as the minimum in 1936 to 20 per cent as the maximum in 1934. This growth may be considered as representing the normal development of the industry, but could be qualified as too low, considering that it coincided with the beginning of the establishment of manufacturing industries in the country. The normal increase of production was slowed down between 1937 and 1944, because of various economic reasons and the internal condition of the country. This also affected the development of other industries. By 1938 practically all public service companies found themselves overloaded and without any reserve capacity.

In 1938 Mexico passed through an abnormally dry year which contributed to the seriousness of the situation of the electrical industry and, as the major portion of power is provided by hydroelectric plants, the resultant scarcity of energy forced the supply companies to restrict the consumption of their customers and to suspend the contracting of new services. Dry years were repeated twice in the period of 1938–1944, thus requiring restrictions on electric energy in 1940 and 1941 and in 1943 and 1944. This period also coincided with the World War II which left Mexico lacking many essential industries and in a condition of severe shortage of power. This again handicapped the increase in industrial production at a time of its maximum need.

Mexico obtained full co-operation and understanding from the United States during the war and was able to obtain permits and priorities for the manufacture of new generating equipment in the United States for existing and new generating plants as well as for other equipment necessary for transmission and distribution of energy. Unfortunately, the heavy burden imposed on American industry by the war necessarily delayed the supply of such equipment and only in 1944 was it possible to increase the generating capacity of the country by the installation of several large new units which partly relieved the power shortage.

A similar effect also could be observed in other industries which found themselves in the unfortunate position of being unable to increase their productive capacity during the war. They could obtain new machinery and equipment only at the end of 1944 and the beginning of 1945, when there was a considerable increase in demand for electrical services.

All this contributed to the reason why, for a period of seven years (1938 to 1944), the total increase of power production reached a figure of only 8.7 per cent, based on the 1937 generation, a figure which is lower than the minimum yearly increase in normal years.

In the year 1945 a considerable improvement in the situation could be noticed, the yearly increase in the generation being 11.5 per cent as compared with that of 1944. In the same year the annual average load factor for Mexico increased to approximately 50 per cent, indicating better utilization of available capacity. It could be increased still further if the load factor could be brought up to 60 per cent by displacing some of the loads from the hours of peak demand or by filling in the valleys.

There are, however, the limitations imposed by the hydraulic resources of the present system, which, as already mentioned, add up to 58 per cent of the total installed capacity in the country. Experience has shown that, in the majority of cases, the present systems cannot increase their output in kilowatt-hours except in very rainy years. Any increase in production has to be provided for by new hydroelectric or thermoelectric plants that can be used as peaking plants as well as for compensating for the shortage of water in dry years, thus permitting a better utilization of the hydraulic resources.

At present, in spite of the fact that substantial generating capacity was added at the end of 1944 and during the past year, the condition of the electrical industry remains critical. It still lacks the necessary capacity for satisfying, during the next three to four years, the demands of the growing industry of Mexico, as well as some indispensable reserve capacity at the plants. Restrictions on the use of power had to be imposed in 1945 as well as this year in some sections of the country.

Figure 2 illustrates the principal electrical supply systems and their relative locations, as well as the location of isolated plants of over 1,000-kw capacity serving some of the industrial centers of the country. No attempt was made to indicate the location of plants smaller than 1,000 kw each, which, along with others, make up a total of 1,266.

## PROBABLE INCREASE IN LOAD AND PROPOSED CONSTRUCTION OF NEW GENERATING PLANTS

Studies made by the Mexican Government, through the Federal Commission of Electricity and public service operating companies, which are based on actual requests for power by various industries as well as on estimations of probable increases due to normal growth indicate that the following production of power will be required in the next four years in order to be able to satisfy the probable demand:

| Year | Production (Million Kilowatt-Hours) | Per Cent Increase |
|---|---|---|
| 1945 | 3,068 | |
| 1946 | 3,460 | 12.8 |
| 1947 | 3,840 | 11.0 |
| 1948 | 4,240 | 10.4 |
| 1949 | 4,660 | 9.9 |

Based on 1945 production the tabulation shows an increase of 52 per cent for the four year period, 1946–1949. It seems necessary, therefore, in order to satisfy

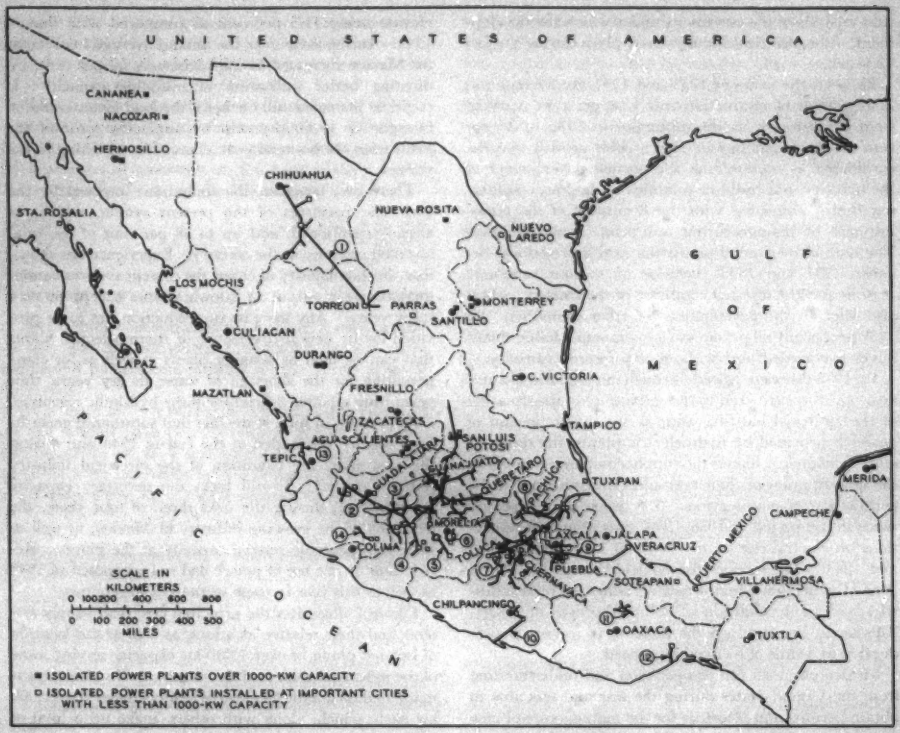


**Figure 2. Location of principal electrical supply systems and of isolated plants over 1,000-kw capacity**

| Number | Name | Total Capacity (kw) | Generation in 1944 |
|---|---|---|---|
| 1 | Laguna Chihuahua interconnected system | 70,320 | 273,000,000 |
| 2, 6, 14 | Chapala system and affiliated companies | 29,087 (Chapala only) | 141,000,000 (Chapala only) |
| 3 | Interconnected system of Guanajuato | 28,860 | 164,000,000 |
| 4, 5, 7, 10, 11, 12, 13 | Electric systems of Comision Federal de Electridad | 28,000 (One unit Ixtapantongo project) | 63,000,000 (Four months Ixtapantongo project) |
| 8 | Mexican Light and Power System | 266,610 | 1,071,000,000 |
| 9 | Puebla interconnected system | 46,533 | 183,000,000 |

the probable demand and to have the necessary reserve capacity, to increase the installed generating capacity and the production of energy over 52 per cent of the existing capacity and production of Mexico.

A program was formulated by the Mexican Government through the Federal Commission of Electricity in co-operation with privately owned public service companies for increasing the generating capacity throughout Mexico. This program includes plans for the installation of new power plants and extensions and amplification of the existing plants to the extent of 400,000 kw during the next four years, or an increase of 53 per cent over the capacity of the existing installations.

It is proposed to install during 1946 and the first part of 1947 a total of 180,000 kw of additional generating capacity for which most of the equipment and machinery has been purchased in the United States. Some of this equipment now is being installed and will be ready for service by the end of this year or at the beginning of the next. Among this equipment is a hydroelectric unit of 39,000 horsepower with a head of 1,040 feet and a 25,000-kw steam turbine unit. The remaining 220,000 kw will be installed in the period from 1947–1949. Part of this equipment also has been purchased in the United States and preliminary installation work is already under way.

The establishment of new plants and an increase in

the generating capacity of existing installations naturally also will require extension and amplification of transmission and distribution systems. It is estimated that the cost of the proposed work for the next four years will be close to 500,000,000 pesos (approximately $100,000,000). The major portion of this sum is to be spent during the present and coming year.

Suppose that by 1949 the population of Mexico reaches 23 million people. The installed capacity per capita then will be 50 watts with a yearly generation of 203 kilowatt-hours per inhabitant, figures still very much inferior to those of the United States. The plans for the electrification of the country probably will have to be revised and amplified by the end of 1949, as there is a definite tendency toward raising the standard of living of the rural element which forms the major portion of Mexican population.

Preliminary studies are being conducted by the Mexican Government and public service companies for further utilization of the natural resources, principally hydraulic, in order to increase the capacity and production of electric energy in preparation for future demands. The natural resources which can be utilized for these purposes are, comparatively speaking, easily accessible and undoubtedly will be of prime importance in the future development of the country. Part II of this article, which will appear in a subsequent issue of *Electrical Engineering*, discusses the possibility of using the hydraulic resources of Mexico as well as those of the oil and coal industries.

# Postwar Engineering Developments

M. W. SMITH
FELLOW AIEE

**Many products of wartime research and development will find a productive place in the postwar world. Some of these, such as radar, the gyroscopic stabilizer, and various new materials already are in the evolutionary stage with definite applications in sight; the potentialities of others, including the most sensational development, nuclear energy, are being explored actively.**

DURING THE WAR years much was said and even more implied about the marvelous things being done in research laboratories and engineering organizations that would have vast and almost revolutionary peacetime uses. Now the question is, "Will these predictions be realized?"

Like the answers to most engineering questions this one, too, is equivocal, neither "yes" nor "no." However, undoubtedly enough of the predicted innovations will materialize to justify the pronouncements of the more realistic prophets but they cannot appear, full-grown, overnight. It should be remembered that many of these marvels of science were reported soon after the seed had been planted in the fields of war. The task now is to transplant them to the fields of peace and then to do a lot of back-breaking work in cultivating them, weeding them, and picking off the bugs before the products can be harvested. These things can be accomplished, but it will take time.

As an illustration of the many war-born developments that are being cultivated for peacetime use a few items may be mentioned that are at present in the transplanting stage.

During World War II the gyroscopic stabilizer did a remarkable job in holding steady the guns of a tank so that the gunner could fire with a high percentage of hits while the tank moved swiftly over rough ground. A modification of this device already has been applied to the stabilization of railroad passenger cars. Recent tests made over a wide range of speeds and varying conditions of roadbeds of the Pennsylvania Railroad show an improvement in riding comfort ranging from two to one to four to one, depending upon the degree of disturbing forces.

The next installation of the ride stabilizer will include a supplementary device to tilt the car body to the proper angle in order to balance the effect of centrifugal force on curves regardless of the superelevation of the track. It is actuated by a pendulous control using a small gyroscope for anti-hunting which recently was built and

Essential substance of an address presented at the AIEE South West District meeting, San Antonio, Tex., April 16–18, 1946.

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tested at the research laboratories of the Westinghouse Electric Corporation.

For the United States Army Air Forces an instrument was developed with a dial which indicates the absolute distance an airplane is above the ground, instead of its height above sea level. This instrument, which obtains its indications from a radar set, can provide absolute altitude above obstacles within five feet. Such a device

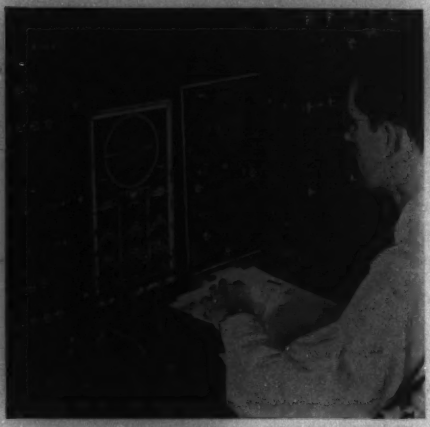


**Figure 1. Transient analyzer presents solution to problem through wave patterns on a fluorescent screen**

*Wave pattern on right screen shows oscillations in current that occur when a short circuit "hits" a generator while that at left indicates resultant mechanical stresses in generator shaft. Results are being studied by G. D. McCann (M '44)*

obviously is a great boon to safety of flight in mountain regions, and during storms and darkness. The absolute altimeter, or some form of it, probably will be adaptable to commercial airplanes.

Radar, of course, will have other peacetime applications. For example, on a recent trip of the vessel, the *City of Richmond*, from Baltimore, Md., to Norfolk, Va., the pilot had before him on a fluorescent screen a map which showed the passing shore line, every obstacle, every buoy—even every rowboat. The principle employed was navigational radar, a direct descendent of military radar. Radar also may be employed for such uses as air traffic control, airplane fog beacons, television relaying, and railway signal communications.

As an offshoot of radar research an entirely new concept of television broadcasting, "Stratovision," has been introduced. In this system the television transmitters will be carried by airplanes cruising six miles above the ground. Programs originating in ground studios will be beamed to the airplanes, then rebroadcast to television receivers in homes. Because television waves, like radar waves, travel in a straight line and do not follow the curvature of the earth, the high elevation of 30,000 feet from which the television signals will be broadcast will increase the range from which the signals may be received satisfactorily from approximately 25 miles to more than 200 miles, and with much smaller capacity transmitters on the airplanes than now are required at the land sending stations.

Because of its novelty and the spectacular part it played in many phases of the war, the term "electronics" often has been overrated and misused by many writers bent on arousing the public's imagination and fancy. Nevertheless, it did play a very important role during the war in many broad fields outside the ultrahigh-frequency field of radar previously mentioned. Its peacetime uses will be just as important. Its possibilities in the field of inductive and dielectric heating alone are too many and too varied to enumerate.

Examples of other items that might be mentioned are the application of electronic excitation systems to large high-speed generators such as the 80,000-kva unit at the Springdale plant of the West Penn Power Company, and a magnetic torque meter for indicating airplane engine output under load by utilizing the principle of the magnetic strain gauge to measure shaft twist.

In considering new products, the importance of materials must not be overlooked. It is often necessary to develop new materials such as special alloys, resins, and plastics to surmount limitations encountered in the course of apparatus developments. One family of high-temperature alloys has strength, ductility, and creep characteristics over a temperature range of 1,200 to 1,500 degrees for different applications. Alloys of this type were employed in the development of gas turbines and jet-propelled engines, and are still one major limiting factor in their future progress.

New materials, such as silicones and "Fosterites," also have been developed in the plastic field. The silicones are high-temperature insulation compounds developed by the Dow-Corning Corporation, which in conjunction with high-temperature materials such as mica and glass, show promise of reducing materially the size and extending the life of electric equipment. The Fosterites (Westinghouse) were used to moisture-proof radar equipment during the war.

Anticipating a step toward substantially higher transmission voltages, an experimental program designed to obtain information for this purpose has been launched through the co-operation of a large power company with several equipment manufacturers. The art of transmission-line design has progressed to the point where practically lightningproof performance is an accepted accomplishment for voltages from 132 to 220 kv and so, from lightning considerations alone, it would not be

necessary in designing a 345- or 460-kv line to increase the insulation or ground-wire spacings. It is certain, however, that corona losses would become prohibitive because even now they are a factor in the selection of conductor sizes and, therefore, because corona will be the controlling factor on higher voltage lines, it is essential to have accurate corona measurements under varying weather conditions.

The test facilities will consist of two $1^1/_2$ mile lines located just outside the Tidd station near Steubenville, Ohio, and arranged so that different conductors can be tested under identical weather conditions, for different seasons of the year, and over a voltage range of from 264 to 500 kv. The necessary equipment is being supplied by the co-operating manufacturers and the whole program is being co-ordinated by Philip Sporn (F '30), executive vice-president, American Gas and Electric Service Corporation. The tests are expected to get under way about the middle of 1946 and to continue for at least a year thereafter.

Increased activity is expected also in the distribution field on the basis of such trends as the extension of network-type of distribution to lower load density areas. Improved relaying schemes, together with banking of transformers, made practical by the introduction of a new type of distribution transformer will help this trend. With appearance becoming an increasingly important factor, particularly in suburban areas, the idea of eliminating the usual pole and aerial circuits by using trench-laid cable and semiburied transformers is another distribution item which is receiving favorable consideration by numerous utilities.

An impressive fact that often stands out in the course of research and development work is the knack of engineers to invent and fabricate the tools and equipment they find necessary for exploration of uncharted fields. An early and now familiar example is the network calculator, on which practically all conditions in power systems can be simulated by electrical constants on the calculating board and a reliable solution quickly obtained.

An important advancement along electrical calculation lines was evidenced recently by the development of the transient analyzer. This mechanical brain provides the means of solving a variety of problems through the use of electrical circuits in which combinations of inductances, capacities, and resistances can be connected in the proper relationships and proportions to represent faithfully the factors in the analogous problem to be solved.

While the realms of mechanics, thermodynamics, electricity, hydraulics, and other branches of science all are governed by their own set of provincial laws, fortunately there is such an orderliness in nature that the laws in one field are analogous to those in another. This fact makes it possible to solve many of the problems in allied fields by the use of the electrical analogue.

As a simple illustration of how the analyzer can be used, consider the problem of determining the short-circuit stress in the shaft connecting the rotating parts of a turbine generator. After calculating the actual values of the masses of the rotors, elastic properties of shaft, and damping characteristics of materials involved, these factors each can be represented in the circuit by proper proportions of inductance, capacity, and resistance respectively. To get at the solution of the problem, flashes of voltage corresponding to the amplitude and time variation of the short-circuit disturbance are applied repeatedly to this circuit by a set of rotating contacts. The resulting electrical waves taken from the appropriate part in the electrical circuit represent the solution to the problem. These electrical output waves are applied to a cathode-ray oscilloscope where they appear as a standing wave that can be photographed or studied. By varying the constants in the circuit until the most desirable condition or performance is indicated by the curve on the oscilloscope, it is possible to show in a relatively short time how improvements can be made in the original system. By changing the factors in the original design to correspond to the change indicated by the constants of the final setting on the calculator, the optimum design can be secured.

While this analyzer cannot produce answers with decimal-point precision, it does give engineering solutions to a variety of problems in a small fraction of the time that would be required by other types of calcu-

**Figure 2. Jet aircraft engine shown in assembly cradle**

*Engine, which is so small that it can fit entirely within the wing of a fighter plane, reduces air resistance virtually to zero*

lating means. The problems solved have varied from the simple illustration mentioned to the determination of the shocks to the grid in a vacuum tube when a crate of tubes is dropped. The time saving in complex cases runs into figures of days and months, and to ratios of 20 or 50 to 1 when compared to conventional calculation methods.

Mention was made earlier of the important bearing high temperature alloys had had upon the development of the gas turbine. Most of the progress made in this field during World War II has been on the jet-propelled engine, a special form of gas turbine developed for use on airplanes. The first jet engines already have been superseded by even more compact and powerful jet engines capable of producing thrusts equal to more than double their weight.

**Figure 3. Radarscope on bridge of ship, City of Richmond, is studied by the captain (left)**

*Unit provides navigational aid and anticollision protection in any weather and in zero visibility within a distance of 100 yards to 32 miles from the ship*

Military restrictions still prohibit the disclosure of the details of construction and performance of latest jet units but it can be said that their performance and reliability justify an optimistic prediction regarding the future use of both the jet engine and the geared gas turbine as important power drives on airplanes. Their light weight, small diameter, and reduced air resistance make them particularly suitable for this application.

Fundamentally, the gas turbine resembles the internal combustion engine in that in each one air is compressed, fuel is injected and burned, and finally high temperature gases under pressure are expanded to produce useful power in excess of that required to compress the air. Because the internal combustion engine uses one structure, a cylinder, for all three functions, its output must be interrupted cyclically whereas the gas turbine which uses separate mechanisms for each of the three functions produces a continuous smooth flow of power.

The normal efficiency of approximately 20 per cent for the simple open-cycle gas turbine at present-day temperatures is still considerably below the efficiency cycle of modern central station steam plants and so cannot be expected to compete as a source of base load power. However, it may find other applications in the power industry, perhaps sooner than is anticipated, for such purposes as peak load units located along existing backbone transmission lines. Perhaps it even may be practical in some instances to gear gas turbines to synchronous condensers and thus supply peak load power at distribution centers without the addition of any electrical generating capacity.

The transportation and marine fields seem to promise further opportunities for application of the gas turbine. A 2,000-horsepower experimental gas turbine has been built and is now on test. It is of the general type applicable to locomotives in combination with electric drives. Research work now being done in an effort to find practical and economical methods of burning powdered coal as a fuel looks promising and may materially accelerate and expand the application of gas turbines to locomotives.

Another interesting development which may have a marked influence on the progress of the open-cycle gas turbine is the free-piston gas generator. This is a form of gas turbine power plant in which the compressor, combuster, and that portion of the gas turbine used to drive the compressor are replaced by a Diesel-type cylinder in which combustion takes place. This cylinder has an extension in which there is a reciprocating free piston for compression of combustion and scavenging air. The high cycle efficiency of this type of plant, which is

well over 40 per cent, results from the fact that the top temperature of the combusted fuel is lowered by expanding it and using the extracted work to drive the compressor.

In any discussion of the commercial possibilities of the gas turbine, the closed cycle merits careful consideration. It provides means of getting around several restrictions which now limit the ultimate possibilities of the open cycle.

For example, it readily permits the use of coal as a fuel without any special preparation because the products of combustion are confined to the air heater and are not circulated through the turbines, compressor, and heat-exchange system. It should be noted, however, that the internally fired unit also has possibilities for such applications as propulsion for naval vessels and large passenger ships. Another important factor, particularly from the central station viewpoint, is that because of the opportunity afforded by the closed cycle to use higher internal pressures, the size of the gas turbine and air compressors can be reduced materially, thus permitting larger unit ratings approaching the limits of the steam cycle.

There seems to be little doubt about the practicability of building and operating a closed-cycle gas turbine. The 2,000-kw unit built and tested in 1939 by the Escher-Wyss Company, Zurich, Switzerland, operated quite satisfactorily from the standpoint of reliability and control, and developed an over-all thermal efficiency from fuel to generator terminals of more than 31 per cent at full load.

With the limited knowledge and operating experience now available, the big question mark seems to be one of economics and the determination of the practical balance between cost and performance. In an effort to get at this factor, a rather complete design and cost analysis of a 10,000-kw closed-cycle unit has been worked out. Cost estimates made on the most favorable assumptions justifiable on the basis of discussions with representatives of manufacturers of boilers and heat-exchanging equipment lead to the immediate but perhaps temporary conclusion that even the closed-cycle gas turbine unit cannot compete effectively with the present steam cycle. This unfavorable economic comparison results largely from the inherently high cost of the air heater and other heat-exchanging equipment.

European manufacturers have given a great deal of thought to the design of air heaters and have developed ideas which show promise of reducing the cost of such equipment to values appreciably lower than those now being considered. If these optimistic hopes can be realized, the closed-cycle gas turbine undoubtedly will find a place for itself in the central station field.

However, even though this goal is realized ultimately, it will come gradually through orderly processes of developmental evolution. Consequently, there is no reason for power companies to be concerned about the likelihood of the gas turbine creating rapid obsolescence in their power generating equipment. But, on the other hand, the gas turbine must be recognized as a potential future possibility that continually must be watched, supported, and evaluated.

When Einstein announced his theory of relativity and the specific relationship between mass and energy 40 or so years ago, it created little commotion outside a small scientific circle. Engineers took note of the statement but considered it to be of philosophical interest only, with no practical significance. This point of view prevailed not so much because there was general disagreement with Einstein's theory, but because few felt that it ever would be possible to find a practical way to release energy locked in the nucleus of the atom. Speculation as to this possibility gradually increased, taking a jump with the discovery of uranium fission in 1939, until a means of producing the chain reaction process was developed during the war, culminating in the atomic bomb demonstrations of 1945.

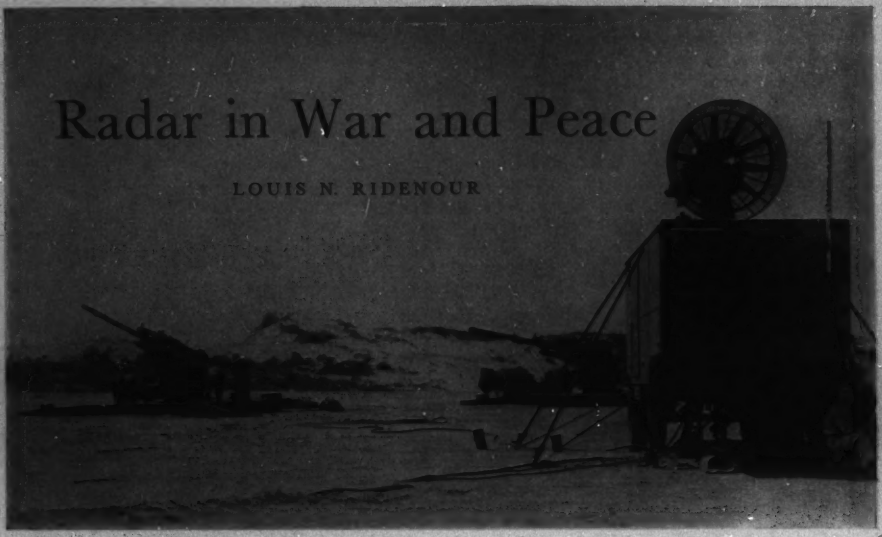
With the proof of the deadly destructiveness of atomic energy as a weapon before them, engineers now are directing their interest toward the prospects for constructive employment of this power. While research will continue on a large scale, development has been so rapid that, with its roots still in the laboratory, useful applications already are being sought in commercial fields. In recent issues of *Electrical Engineering* basic concepts of nuclear energy and the chronology of its development, as well as possibilities and economics of future applications, were discussed. There is little to add to those data at this time.

One big problem presented by the industrial application of atomic energy is the accomplishment of heat transfer at temperatures high enough to be applicable to modern high-efficiency heat engines. The appreciation of this fact already has led to some unsound proposals. However, we can be reasonably sure that somehow, some time, somebody will get a bright idea that, together with other steady evolutionary progress in this field, will make atomic energy a practical and economical source of power in commercial fields. Again, there is no apparent reason for power companies to fear rapid obsolescence from this source.

Here is another example of scientific progress that has great potential possibilities. Any basically new idea will have ramifications beyond our present comprehension and vision which will become apparent only with time and research. On the whole, progress still will be made in gradual evolutionary steps. However, it is certain that engineers and scientists will continue to make new discoveries; new ways to generate and utilize power, new ways to heal and save, even new ways to kill and destroy if necessary. What does this mean in terms of a better life? That will depend upon our world leaders and their success in devising a method which will insure a peaceful social, economical, and political future.

# Radar in War and Peace

LOUIS N. RIDENOUR



**The use of radar as a defensive warning signal and guide for antiaircraft fire as well as a control for offensive warfare was one of the chief advantages enjoyed by the Allies during World War II. In the postwar world, however, radar will have even more far-reaching effects as the most important element in the development of a completely safe navigation and traffic control system for both sea and air.**

RADAR IS A COINED word compounded of the initial letters of "radio detection and ranging." The phrase really should be "radio direction-finding and ranging," for the direction and range of a target are the two basic data which radar has to offer. Most of the radar equipment in present use is "pulse" radar in which the transmitter sends out a short burst, or pulse, of energy in the form of radio waves, and then is turned off long enough to permit the receiver to pick up the echoes of this pulse returned by radar targets in the neighborhood.

## HOW RADAR WORKS

As the radio pulse travels to the target with the speed of light (186,000 miles per second) and the echo travels back to the radar set with this same speed, the time elapsing between the transmission of a pulse and the reception of an echo is a measure of the distance between the radar set and the echoing object. These times are very short, of course. An object one statute mile from the radar set will return an echo about ten millionths of a second after the pulse is sent out. But such extremely short time intervals can be measured, by the techniques of modern radar, with a precision which seems uncanny.

The transmitter and receiver of a radar set ordinarily share the same antenna as they work alternately. The transmitter sends its pulse (normally about a millionth of a second long), then waits for a relatively long time, during which the receiver is gathering the returning echoes, before sending out the next pulse. In order to establish the direction of a target, this common antenna is usually highly directional, so that echoes are received only from the direction in which the antenna is pointing. The antenna is arranged so that it can be moved mechanically to sweep the radar beam, like the beam of a searchlight, over the volume of space to be investigated.

Echo signals from radar targets are pulses like the outgoing pulse, but many times weaker. The transmitted pulse may be at a power level of millions of watts; the power in an echo seldom exceeds $10^{-10}$ watts, and may be much lower. Careful attention must be paid to the design of radar receivers in order to keep their inherent noise as low as possible, so that the weakest possible echoes can be distinguished.

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Essential substance of an address presented before a meeting of the AIEE New York Section, November 14, 1945.

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The display of radar signals, except for special purposes, should reproduce the quantities—direction and range—given by the radar set. The most generally useful and most generally used display is called PPI, or plan position indicator. In the PPI, the normally cut-off intensity grid of a cathode-ray tube is modulated with the output of the radar receiver, so that bright spots will appear on the screen of the tube only at the instant an echo is being received. The deflection of the cathode-ray beam is accomplished in two co-ordinates. A fast radial sweep outward is begun at the instant each transmitted pulse is sent out. This sweep is linear, and when the beam reaches the edge of the screen, it is returned to the center of the tube in readiness for the next transmitted pulse. Since the time elapsing between the transmitted pulse and the return of the echo is a measure of the range to the object causing the echo, bright spots representing echoes will occur along this radial sweep at distances from the center of the tube which are proportional to the ranges of the echoing objects from the radar.

The direction in which the radial sweep takes place is caused to correspond to the direction in which the antenna is pointing momentarily. Thus, we might agree that the top of the cathode-ray tube face corresponded to north, as measured at the radar antenna. Then, when the antenna is pointing east, the fast radial sweep which follows the transmission of each pulse takes place from the center of the cathode-ray tube horizontally to the right. When the antenna is pointing south, the radial sweep goes downward from the center of the tube, and so on.

The result of all this is that the PPI reproduces, in miniature, a plan view of the surroundings, showing all the radar targets in the vicinity in their proper relation to one another and to the radar set. The position of the radar set itself is in the center of this display and distances and directions of all targets are shown correctly.

Radar echoes are returned by objects which stand out sufficiently above their surroundings to be distinguishable from them; ships on the surface of the sea, coast lines, hills, buildings, aircraft or birds in the air, clouds containing precipitation, and the like. The relative strength of the echoes from different targets depends in a very complicated way on the wave length used by the radar, the aspect in which the target is viewed, and other factors.

A radar set is not able to distinguish two targets as separate unless they are separated in azimuth by more than the width of the radar beam, or in range by more than the distance corresponding to the length of a pulse, or both. As the width of the radar beam is proportional to the wave length divided by the width of the antenna, ability to resolve targets close together demands large antennas, short radio wave length, and short pulses.

This ability to resolve—to present a picture of high definition in the television sense—is so important that one of the major effects of the radar development carried on during the war has been to exploit regions of wave length which were laboratory curiosities in 1940. Most modern radar sets built during the war operated in the vicinity of 10-centimeter wave length, much air-borne radar operated near 3 centimeters, and even shorter wave lengths were being used as the war ended. Pulse powers attained by microwave transmitters were as high as 4 million watts, and the sensitivity of receivers was within a few decibels of the theoretical noise limit.

While the definition and resolution of PPI pictures produced even by the most modern microwave radars are somewhat disappointing to one who is used to the microscopic detail of visual photography, the absence of the effect of perspective, the ability to see under any conditions of optical visibility (through fog, rain, snow, or darkness), the provision of exact information on target range, and the great distances at which targets can be seen (200-mile range on a large airplane is not unusual performance), are all superiorities of radar vision to optical vision.

## RADAR ON ALL FRONTS

The story of radar's participation in the war has been told so well and widely that only some of its bolder outlines need be sketched. From the early Pacific naval

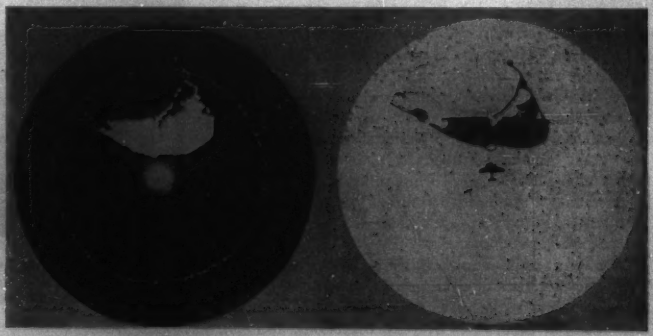

**Figure 1. Comparison of PPI display of Nantucket Island with chart of same area**

*Picture is one of the first made (1942) with an air-borne 3-centimeter radar set. Range circle has radius of ten nautical miles*

**Figure 2. Scope shot of a typhoon taken by units of a United States Naval Force operating off the Philippines on December 18, 1944**

*Typhoon, not yet fully developed, was moving in a west-northwesterly direction at an accelerated speed with seas at plus 40 feet. Eye of typhoon is clearly visible*

battles and the Battle of the Atlantic to the final capitulation of Japan, reeling under blows from radar-guided B-29s, radar was one of the main technical superiorities the United States enjoyed over its enemies.

At first, it was thought that radar's only use was in air defense, and its success in this role during the Battle of Britain strengthened this impression. While radar never lost its usefulness in this defensive role, it promptly was forged into a weapon of offense as the war went on.

Air-borne radar played an indispensable part in the Atlantic antisubmarine campaign which reached its peak during the spring and summer of 1943. The then-new microwave sea-search radar dealt the U-boat fleets a blow from which they never recovered, and so destroyed the morale of the German submarine service that their psychology changed entirely from one of attack to one of defense. During much of 1943, U-boats were sunk at a rate not far from one per day, two-thirds of them by aircraft attack. Most of these attacks developed from radar contacts.

The accuracy of antiaircraft fire was increased greatly by the development of radar position-finders which gave accurate target range under all conditions of visibility, and could, at night or in overcast conditions, also give directional information nearly as good as that available from optical tracking of the target. The most spectacular successes of radar-guided antiaircraft batteries came in the defense of London (and later of Antwerp and Brussels) against attacks by the German V-1 buzz-bomb. The defense efficiency achieved in these campaigns, after an initial shake-down period, quickly reached a figure of better than 90 per cent, which reduced V-1 from a serious threat to a bothersome, but insignificant, irritation. Most of the success of the V-1 defense is attributed by the British to the superb radar with which the American batteries were equipped.

As the Eighth Air Force built up in strength during 1943, it became obvious that the poor target visibility which characterizes European winter weather seriously would limit the operations of this great strategic air force unless some device which permitted the bombing of unseen targets were available. Radar did this job, too. By the fall of 1943, an experimental squadron equipped with radar designed to permit bombing through the overcast, or through the artificial smoke with which the enemy blanketed his cities, was available to lead the combat airplanes of the Eighth Air Force. In December 1943, the Eighth Air Force equalled the Royal Air Force Bomber Command in tonnage dropped, and in January 1944, it surpassed the RAF tonnage—though in all this period there were only four raids in which visual sighting of the target was possible. The rest of the bombs were aimed by radar.

By the time the B-29s were dispatched to the Pacific for the strategic air campaign against Japan, the necessity of radar bombing equipment for a strategic air force was obvious. Each B-29 was fitted with a radar bombing device. These found considerable use, for the Japanese weather, in respect to target visibility, is con-

**Figure 3. Time exposure taken on the south coast of England in August 1944 showing the interception of a buzz bomb by 90-millimeter radar-aimed fire**

*Streak of light at right is caused by glow of V-1's jet engine while flash indicates bomb's explosion. Predicted gunfire, evidenced by dots of light, follows path bomb would have taken if it had not been shot down. Equipment used was similar to antiaircraft radar position finder illustrated in title photograph*

siderably worse than that in Europe.

A concrete example of the way in which a radar can be transformed from a defensive to an offensive role is afforded by a large ground-based microwave radar which reached the European war in the spring of 1944. Its designers first conceived this set as a fixed installation to give long-range coverage against low-flying enemy aircraft for supplying early warning to the air defense organization. By the time it was available for use in the war, the United States had achieved substantial mastery of the air, and the need for an early warning radar was very small. The set first was used, from a fixed site on the English side of the English Channel, for controlling offensive sweeps made by friendly fighters against then-occupied France. Its success in this role was so great that several similar sets were rebuilt, in Europe, to be transportable. These were carried along with the control organizations of the United States Army Air Forces Tactical Air Commands, and used for the control of friendly fighter-bombers during and after the invasion of Normandy.

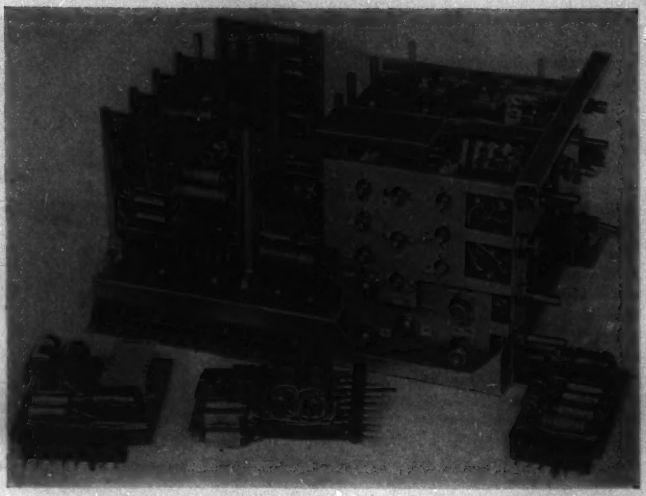

**Figure 4. Chassis illustrating extreme compactness made possible by use of miniature techniques and flexibility afforded by detachable subassemblies**

*Unit measures 6 inches by 9½ inches by 12 inches and contains 50 tubes as well as some bulky mechanical components*

In its new offensive role, the set was phenomenally successful. It enabled fighter-bombers of the Tactical Air Commands to be guided to their targets and brought back to their bases under conditions of poor visibility. It enabled American fighters to tackle the occasional Luftwaffe sorties under the most favorable conditions; and, in the hands of the strategic air forces, it enabled rendezvous of bomb formations and escorting fighter groups to be made with ease and precision at distances up to 200 miles from the radar station.

Not more than a brief sketch of some of the ways in which modern radar contributed to the winning of the war has been attempted here for, after all, the war is won. The pertinent question is, "What is the place of radar in the postwar world?"

## RADAR IN THE POSTWAR WORLD

Clearly, the chief direct and immediate contribution radar can make to a peaceful world lies in its ability to render air and sea navigation entirely safe, continuous, and foolproof, regardless of visibility. Long-range pulse navigation schemes closely related to radar can be relied upon for en route navigation over the broad expanses of the air or the sea. Collisions of ships with icebergs or derelicts, or of aircraft with mountains, buildings, or other aircraft may require the further provision of radar equipment integral with the vessel. Such integral radar also will provide independent means for the vessel to navigate by pilotage in harbors or narrow waters, or near airports.

In addition to the devices already mentioned, two other adjuncts of modern radar promise to be useful in the problem of air and sea navigation and traffic control. These are the radar beacon, and means for relaying radar displays by a radio link from the station where they are obtained to distant points.

The radar beacon is an echo magnifier in principle. It is a device with a receiver whose output is caused to trigger a transmitter which sends back a strong pulse, or coded sequence of pulses, to the radar set whose pulse caused the triggering. The time delay between reception of a radar pulse by the beacon and transmission of the reply pulse by the beacon receiver can be kept very small, and in any case is kept constant, so that range and direction to the beacon can be measured in just the same way as range and direction to any radar target are measured. The beacon has the advantage that its reply is very strong compared to an echo, so that

it can be seen at great distances, and further that, since its reply can be coded in a characteristic way, unique identification of each beacon is possible. In effect, the beacon is a radar lighthouse.

By means of more or less standard television techniques, the video signals coming from a radar receiver, and suitable synchronizing signals, can be applied as modulation on a wide-band carrier, and the vital information provided by a radar set thus transmitted to a radio receiver at a distant point. The output of this radio receiver can be used to operate a PPI, or another type of radar indicator. Thus, with a relatively light and simple installation, the complete display of a heavy and powerful radar set can be reproduced at other places. This has been suggested, for example, as a means of providing commercial airliners with a continuous radar display, relayed to them from powerful radar stations along the airways, without necessitating the carrying of integral radar equipment in the airliner itself.

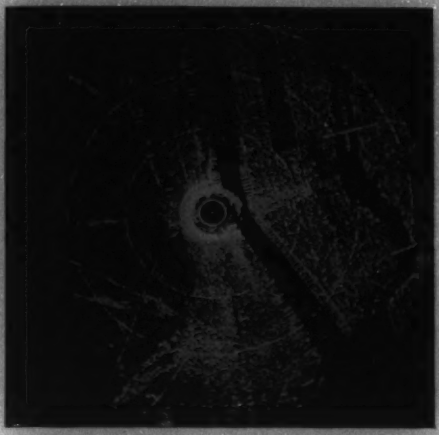

**Figure 6. Lower Manhattan as seen on the PPI of an air-borne radar set**

*The outline of Central Park can be distinguished as well as docks along the Hudson River, bridges over the East River, railroad lines in New Jersey, shipping in the rivers and harbor, and so forth. Difference in radii between successive circles of constant range is one mile. Small blank spot in the center is due to the absence of signals out to a range corresponding to the altitude of the aircraft*

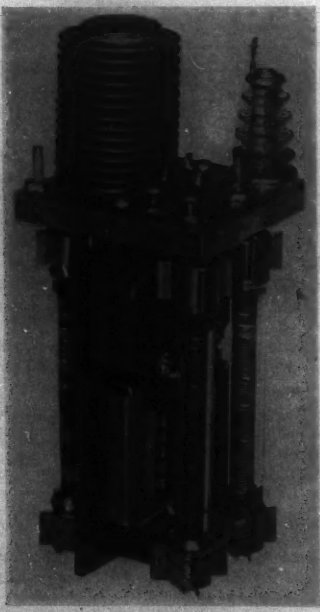

**Figure 5. Miniature high voltage supply for cathode ray tube (approximate size)**

*External 6V6 tube is used as an audiofrequency oscillator. Can contains transformer (2,500 cycles), selenium rectifiers, and filter. Bellows is for expansion of cooling oil*

At present, it is not clear just how these various types of radar and allied facilities will be integrated into a navigation and traffic control system for the air lanes and sea lanes of the world. It is clear, however, that the embarrassment of decision is one of riches. Pulse navigation systems, integral radar, radar beacons, and relay radar, considered together, provide more than sufficient facilities for coping with the problems of en route navigation and of pilotage in the vicinity of harbor or airport.

In the case of aircraft, the problem of actual landing approach is also an important and difficult one. Present systems of instrument approach are adequate from the point of view of safety, but their traffic-handling capacity is so low that serious jams occur even today at major airports under instrument conditions. Several schemes, of which one of the most promising is GCA (ground-controlled approach) radar, have been designed to deal with this problem. The GCA is ground-based equipment of high resolution which displays to a ground controller sufficiently detailed and accurate information of the position of an aircraft on final approach to permit the controller to "talk" the plane into its correct glide path by radio instructions to the pilot. It thus requires no additional equipment in the airplane, beyond the communications equipment which must be carried

anyhow. In use by the Army Air Forces at the end of the war, this system gained much favor for its simplicity and effectiveness. It is not clear that the finally adopted landing aid will be GCA; but it is clear that microwave radar offers a facility which can do the job.

## HERITAGE OF RADAR

Not the least important of the effects produced by the wartime work on microwave radar is the detailed improvement in techniques vital to many branches of engineering, and to scientific instrumentation for many purposes. In the brief scope of this article, it will be possible to mention only a few outstanding examples.

One of the most spectacular is the great extension of the radio-frequency spectrum. At the beginning of the war, 200 megacycles per second was considered about the highest frequency for which radio techniques were routine. At the end of the war, this limit had been extended to upward of 20,000 megacycles per second. On the assumption (which is nearly realizable) that the width of channel required for a radio service is fixed by the band-width required for the service, with small allowance in channel spacing for frequency instability, this means that the number of available radio channels has been multiplied a hundredfold. Actually, since microwaves are not reflected from the ionosphere and ranges do not extend much beyond the optical horizon, the number of services which can be maintained in the United States or in the world has been increased still further.

The necessity for exact measurement of radar range has vastly improved the ability to time small intervals. The radar antiaircraft position finder, for example, routinely measures range to an accuracy of about 15 yards, which means a measurement of time accurate to the nearest tenth of a millionth of a second. With a little care and attention to details, similar sets (which have been used to track shells, bombs, and rockets in flight for the establishment of ballistic tables) have measured time accurate to plus or minus a hundredth of a microsecond.

A third important advance was brought about by the need for making the complicated circuits of radar light, compact, and economical of power, in order to cut down the expense of installing radar in high-performance aircraft. This has led to many striking advances in the use of miniature components such as tubes, resistors, and capacitors, and in design and assembly techniques which exploit to the fullest the inherent compactness of these components. The use of sockets, universal before the war, carries the implication that vacuum tubes are interchangeable (and thus that they are the least reliable circuit components and the most likely to need changing), and provides the most important tie points for the wiring. The modern trend has been to wire the tubes directly into the circuit which saves the bulk and weight of a socket. Furthermore, it assumes that the tubes initially installed in a circuit will not be changed, so that the circuit constants do not have to be arranged to accommodate the whole range of variation in vacuum tube properties. This enables much more efficient circuit adjustment and operation. High-frequency a-c power supplies also have been exploited to cut down the weight and bulk of transformer–rectifier–filter combinations.

Tremendous improvements in the design of cathode-ray tubes and in sweep circuits and auxiliary equipment followed the manufacture of tens of thousands of radar indicators during the war. It seems safe to predict that the cathode-ray tube indicator will be used as a precision device for the display of data in most postwar instrumentation involving rapidly varying quantities.

The United States invested more than 200 million dollars in radar research and development during the war years, and more than ten times that in the manufacture of service radar equipment. Ten thousand or more technical man-years were spent on development and engineering design. The fruit of all this work and money was not merely a weapon, though a superb weapon which was decisive in many campaigns did result, but also a variety of powerful and promising techniques which will make their influence felt far from the narrow field of radar.

**Figure 7. TR boxes, devices which switch radar receivers to and from the antennas 1,000 times a second (approximately half size)**

*The switch is essentially a needle spark gap in a confined space containing gas at a definite pressure. A relatively large glass reservoir acts as a gas chamber and also as the necessary high voltage insulator*

# The Amplidyne

JOHN R. WILLIAMS

**This article explains the characteristics and operating principles of the amplidyne generator by comparison with a conventional d-c generator. The fact that the amplidyne possesses the requirements for a perfect electric regulator, high amplification and fast speed of response, is emphasized, and several applications are described which illustrate the amplidyne's versatility.**

AN AMPLIDYNE is an amplifier with the characteristics of a rotating machine. It is related closely from the standpoint of operating principle to the Rosenberg generator and the metadyne, differing principally in its use. The Rosenberg generator is a constant-current source of d-c electric power, the metadyne in its usual form is a machine for converting constant-potential d-c energy into constant-current d-c energy, while the amplidyne generator is a dynamoelectric amplifier.

A disassembled amplidyne generator is shown in Figure 1. Externally, it is similar in appearance to any d-c motor or generator. It has the necessary components of a rotating device and a d-c machine. The armature is electrically and mechanically of conventional type, but the stator structure internally resembles that of an induction motor.

The principles of amplidyne electrical performance can be explained best by comparison with a conventional generator, for example, a 10-kw 100-volt 1,750-rpm separately excited d-c generator driven by a prime mover of the proper horsepower and speed. For rated output a field excitation of 2,500 ampere turns per pole is required and approximately 100 watts are required to produce the necessary ampere turns in the magnetic structure. The amplification, therefore, is 100 to 1 and thus it is basically an amplifier.

The 10-kw generator is designed for 100-volt field excitation. With a resistance of 100 ohms and 2,500 turns per pole, a current of one ampere flows in the field circuit which produces a magnetomotive force and a flux which travels from pole to pole through the revolving armature. The rotation of the armature through this flux produces a potential of 100 volts across brushes placed at points where the armature conductors cut a minimum of flux. If a 1-ohm resistor is placed across these brushes, a current of 100 amperes flows out of the armature from the positive brush, and back into the armature at the negative brush. (Armature resistance drop is neglected.) This current flow produces the well-known "armature reaction" flux.

In general, the field and armature reaction fluxes may be considered numerically equal, but at right angles to each other. The armature reaction distorts the field flux by pushing it in the direction of rotation and from this it readily can be seen that armature reaction generally is undesirable. However, the amplidyne uses this same armature reaction flux to advantage. If a small voltage is applied to the field circuit, a small armature voltage will be generated which then will produce a large current flow in the short-circuited armature. Assuming 10 per cent inherent armature circuit resistance, 10 volts applied to the field will produce a current flow of 100 amperes at 10 volts in the armature circuit. This current will produce an "armature reaction" flux of the magnitude formerly obtained with full field excitation and a load resistor of one ohm.

The armature now is rotating through two fluxes; the small field flux and the armature reaction flux. The voltage generated by rotation through the field flux is used by the short circuit, but the voltage developed by rotation through the armature reaction flux is still available for use. As the armature reaction flux is numerically equal to but displaced 90 degrees from the excitation flux produced by the former field with 100 volts applied to it, the second armature voltage equal to 100 volts is available at points displaced 90 degrees from the first.

In Figure 2, two additional brushes are shown dis-

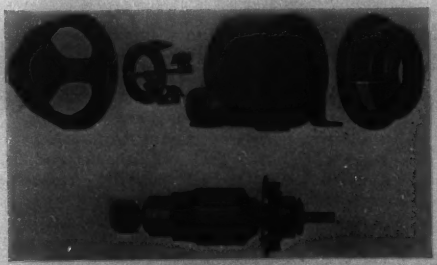

Figure 1. View of disassembled amplidyne generator

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placed 90 degrees from the original brushes, and across them appears the rated potential of 100 volts.* If the original 1-ohm resistor is placed across these brushes, a current of 100 amperes will tend to flow, but the flow of current into this resistor produces a second component of armature reaction flux as shown by the solid circles.

From the flux vector diagram it is apparent that this second component armature reaction flux is in direct opposition to the small control field flux. Because it is much larger than the field flux, the load armature flux will collapse the circuit and both the load voltage and current will decrease to a small value. To avoid such an occurrence, a compensating field coil, mechanically situated on the field poles and electrically connected in series with the load, is added to the machine. This compensating field produces ampere turns in direct opposition and numerically equal to the ampere turns produced by the load current. The net effect during steady states is to leave two operating fluxes, that is, the control field flux and the short-circuit armature reaction flux. The field power is now only 1 watt and produces 250 ampere turns and is controlling 10 kw on the armature side of the circuit. Thus the amplification is 10,000, a decided improvement over the conventional 10-kw generator which has an amplification of only 100.

From the foregoing, it can be seen that the first requirement of a good regulator, high amplification, has been met. A machine still is needed, however, which will respond rapidly to a change in control field power. In the conventional 10-kw generator, after the voltage has been applied to the field, approximately 1/2 second is required until the armature has 100 volts across its brushes. This delay is due to the time of build-up of the field current.

In all types of machines, the ratio of inductance to resistance can be decreased by design changes and, consequently, the time of voltage changes also can be decreased. For example, the 10-kw conventional generator can be made to build up in the fast time of 0.05 second by a change in this ratio. Such a procedure, however, increases the power needed for excitation to such an extent that 5 kw is required. With the 10-kw armature output controlled by 5 kw, the amplification would be only 2 instead of the normal 100. Yet the amplidyne has an extremely fast build-up time and still retains its high amplification.

* In this and succeeding diagrams the compensating and main field winding have the same magnetic axis as the armature load current.

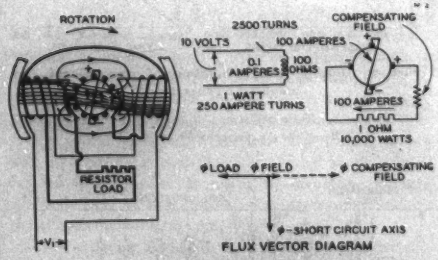


**Figure 2. Diagrams of amplidyne generator**

*Amplification = 1 watt to 10,000 watts or 10,000*
*Build-up time = 0.05 second*

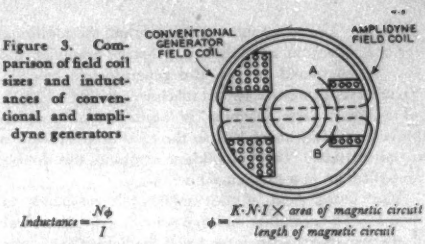


**Figure 3. Comparison of field coil sizes and inductances of conventional and amplidyne generators**

$$\text{Inductance} = \frac{N\phi}{I} \qquad \phi = \frac{K \cdot N \cdot I \times \text{area of magnetic circuit}}{\text{length of magnetic circuit}}$$

($K$ = permeability, $N$ = number of turns, $I$ = coil current, $\phi$ = flux)

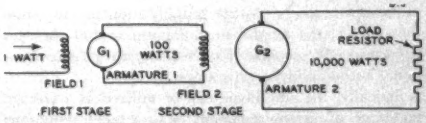


**Figure 4. Two stage power amplification using two machines**

*Amplification = 1 watt to 10,000 watts or 10,000*

In Figure 3 a rough comparison of the field coils of a conventional d-c generator and an amplidyne generator is shown. As previously stated, conversion of a conventional 10-kw generator to an amplidyne reduces the field excitation from 2,500 to 250 ampere turns, which permits a further decrease in the physical size of the pole structure as less material is needed to accommodate physically the field coil. Because of this, the portion of the pole which is nonessential ($A$–$B$) can be removed and the remaining pole and field coil can be brought closer to the armature. From the formula in Figure 3, it can be seen that a reduction of the length of the magnetic circuit will produce a larger flux per ampere turn. Such a reduction is cumulative and the final result in a 10-kw amplidyne is:

1. A field excitation requirement of 25 ampere turns at 1/5 watt.
2. An amplification of 50,000.
3. A magnetic structure which responds rapidly to a change in excitation power.

However, there is one other feature which contributes to the speed of response in an amplidyne—the armature circuit. Armatures have minute inductances as compared with field circuits and armature voltages change almost simultaneously with changes in the field flux

strength. Due to the short-circuit axis and the additional set of brushes, an amplidyne is a 2-stage amplifier and can be compared to two d-c generators in cascade. Figure 4 illustrates a 100-watt machine exciting a 10,000-watt unit. Each machine is assumed to have an amplification factor of 100, so the total amplification is equal to 10,000. The amplidyne combines this double amplification in a single machine.

The control field of the amplidyne corresponds to field 1. The armature and short-circuit axis correspond to the armature of generator 1 and the field of generator 2, and the amplidyne armature to the armature of generator 2. This explains the amplidyne symbol which is given in Figure 5. Because of the minute field circuit inductance and the 2-stage amplification in the armature circuit, the amplidyne builds up to 100 per cent voltage in 0.05 second. Figure 6 compares the conventional and amplidyne generators.

Basically, the amplidyne can be utilized as a voltage regulator, a current regulator, or as a speed regulator. First, consider the amplidyne controlling voltage. A cardinal principle of a regulating system is that an ideal or standard must be used as a reference for performance. This can be illustrated by a brief review of a mechanical regulator with a system as set up in Figure 7. Here a conventional generator is used to supply several small motors. The inherent load characteristic of the generator is a drop in voltage from no load to full load. To correct this, a mechanical regulator consisting of a spring balanced against the magnetic force of a coil, and a resistor stack, is used to vary the generator field current and to maintain a constant value of generator voltage $V_2$. The coil is placed across the generator lines and will produce a force proportional to the voltage $V_2$. Any variation of $V_2$ from the desired value upsets the balance of the spring and the coil, and the resistor stack then is adjusted to change the field current to return $V_2$ to the desired value. In Figure 8 the amplidyne is shown performing the same function.

To follow the principles of regulating systems, one field comparable to the spring of a mechanical regulator is used as a reference field and is excited separately. A second field is placed across the generator lines which compares to the coil of the mechanical regulator. This field is the voltage control field and is in opposition to the reference field. Because of the small space required for amplidyne control fields, 4, or even 5, may be incorporated in the amplidyne stator structure without sacrifice of size or operation. As practically all amplidynes from 200 watts to 20 kw require only 25 ampere turns for full excitation the reference field which produces positive amplidyne output must be 25 ampere turns larger in strength than the voltage control field. The reference field is designed for approximately 125 ampere turns and the voltage control field for 100 ampere turns which leaves a net of 25 ampere turns when the voltage $V_2$ is at its 100 per cent value. Using field strengths of

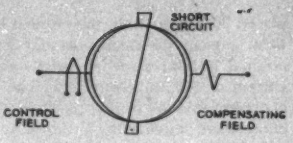


**Figure 5. Amplidyne symbol (two stage power amplification in one machine)**

large ampere turn values makes adjustment to 25 ampere turns simple and, in addition, provides a source of forcing power for the amplidyne. For example, when the external voltage $V_1$ is applied to the reference field, the 125 ampere turns force the amplidyne to build up at the rate of 2,000 volts per second for a 125-volt machine or at 4,000 volts per second for a 250-volt machine. The change in net ampere turns in the amplidyne is shown in Figure 8*A*. Figure 8*B* shows a similar curve which illustrates the voltage wave produced by the amplidyne armature as the ampere turns travel their portion of the cycle. The difference between the peak of the voltage wave and the steady state value as given in Figure 8*B* illustrates the forcing characteristic of an amplidyne which removes the time delay caused by the generator field inductance.

As the generator field current and armature voltage build up, the voltage control field also builds up until 100 ampere turns are produced. At this time, only the necessary 25 ampere turns are available for excitation which is the needed amount for 100 per cent voltage. If motors are loaded on the system, the generator voltage $V_2$ also changes, but is held constant by the amplidyne in this manner. Assume that $V_2$ tries to drop to 90 per cent which would weaken the voltage control field to 90 per cent of 100 ampere turns. This would leave a net excitation in the amplidyne of 35 ampere turns which

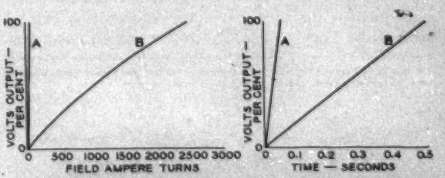


**Figure 6. Output voltage build-up of conventional and amplidyne generators**

*A—10-kw amplidyne*
*B—10-kw d-c conventional-type generator*

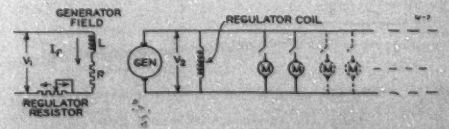


**Figure 7. Mechanical regulator holding constant voltage**

would boost the amplidyne output and increase the generator field current and the voltage $V_2$. This, in turn, strengthens the voltage control field until it again has a strength of 100 ampere turns when $V_2$ is again equal to 100 per cent and again the net of 25 ampere turns exists in the amplidyne. The reverse is true if motors are removed from the system and the voltage $V_2$ tries to rise. Figure 8*C* demonstrates the rapid change in generator field current as motors are loaded and unloaded from the system.

Figure 9 shows the amplidyne acting to maintain constant current flow into the battery independently of the rise in battery voltage with an increase in the state of charge. Again two control fields are used, one the reference field and the other a current control field excited from the resistance drop across a shunt connected in the generator line which is directly proportional to the load current *I*. As the battery becomes charged, its voltage rises and the difference between the generator and battery voltage decreases, tending to lower the current *I*, to decrease the resistor drop across the shunt, and to decrease the strength of the current control field. The final effect is that the reference field boosts the amplidyne output and increases the generator field current and generator voltage until current *I* is back to its 100 per cent value.

The amplidyne used as a speed regulator is portrayed in Figure 10. The speed of a d-c motor whose field is excited separately from a constant voltage is proportional to the voltage applied to the motor armature terminals. If load is applied, the motor speed will tend to drop because of the inherent characteristics. To hold constant speed independently of load, the amplidyne must adjust its armature voltage $V_2$. In the amplidyne, two fields again are used; the reference field and a speed control field. A small permanent-magnet generator driven from the motor shaft supplies a voltage to the speed control field which is proportional to the motor speed. Any deviation of the motor speed produces a change in the strength of the speed control field and thus changes the amplidyne output to bring the motor speed back to the desired value.

In all of the foregoing cases the control fields were used for regulating purposes. They also may be used to function as limits (Figure 11) in an adjustable-voltage variable-speed d-c drive in which the amplidyne is substituted for the conventional exciter for the generator. The reference and voltage control fields are very similar to the system previously described (Figure 8), except that an adjusting rheostat has been added to the voltage control field to raise or lower the generator voltage which is held at any preset point determined by the position of the rheostat arm.

However, now added to the system are current and speed limit fields to each of which have been added a source of external d-c power and a blocking rectifier either of the copper oxide or selenium type. For explanatory purposes, the current limit circuit has been shown alone at the right-hand side of Figure 11. The output of the external direct current is opposed by the resistance drop across the shunt and the current limit field is placed between these two opposing voltages. If the external direct voltage is higher than the shunt voltage, current will flow to the right. However, this would cause the current limit field to aid the reference field and instead of limiting would increase the current. To avoid this, a rectifier is used to block current flow into the shunt and current is allowed to flow only from the shunt into the external d-c source. This flow occurs only when the shunt resistance drop is higher than the external direct voltage. With such an arrangement, the current field is inactive until the generator load current becomes high enough to produce a resistance drop across the shunt higher than the external direct voltage, at which point the current limit field opposes the reference field, thus finally weakening the generator field and, consequently, lowering the generator voltage and current.

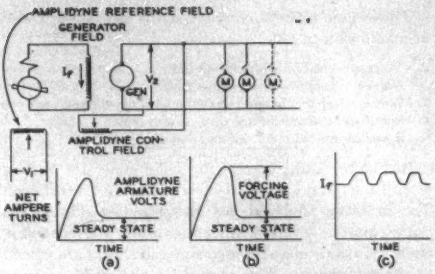


**Figure 8. Amplidyne acting as voltage regulator**

*A—Change in net ampere turns in amplidyne*
*B—Voltage wave produced by amplidyne armature*
*C—Change in generator field current where amplidyne is used*

The same principles apply to the action of the speed limit field. When the motor speed is excessive, the speed voltage generator passes current through the speed limit field and bucks the reference field. The final result is a lowering of the voltage $V_2$ and a return of the motor speed to normal.

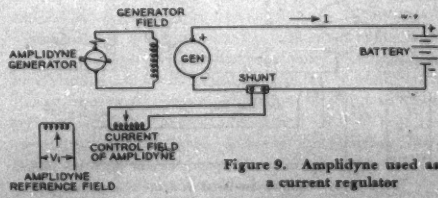


**Figure 9. Amplidyne used as a current regulator**

These basic types of control circuits can be combined in many ways to give:

1. Voltage regulation with current limit.
2. Current regulation with voltage limit.
3. Either voltage or current regulation with speed limit.
4. Speed and voltage control with current limit.
5. Speed control with current and voltage limits.

In Figure 12 the control for a d-c generator feeding several d-c motors on an electric power shovel is shown. The problems involved are recognized readily as the bucket must be reversed with either lifting or overhauling loads. In addition, severe strains and shocks are placed on the equipment. This control circuit employs voltage control with current limit.

1. Current limits, both plus and minus, protect the complete equipment from excessive electrical loads and mechanical strains as shown in Figure 13.

2. The d-c motors can be plugged and reversed without excessive current flow during low speeds or stalled conditions.

3. The combination of voltage control and current limit forces the load to a maximum under rapidly changing conditions thus increasing production by maintenance of the highest rate of acceleration and deceleration.

Such a system is suited for skip hoists, machine tools, steel mill apparatus, and saw mill carriages.

A useful characteristic of the amplidyne is its ability to control the position or speed of several machines from a master control. For example, where two d-c motors are supplied from a constant voltage bus, the field of motor 1 with an adjusting rheostat also is supplied from this bus, but the field of motor 2 is excited by an amplidyne generator. The amplidyne has both a reference field and a speed control field. To the shafts of each motor are coupled speed voltage generators and the speed field of the amplidyne is placed between the opposing voltages of the speed voltage generators. With this arrangement a difference of the motor speeds excites the speed field to either buck or boost the reference field and bring the motors back to similar speeds. Adjustment of the rheostat in field 1 will change the speed of motor 1 and the amplidyne rapidly changes field 2 to bring the two motor speeds in step with each other.

Variations of this speed control scheme are used also

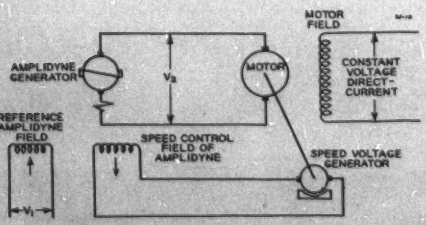


**Figure 10. Amplidyne used as a speed regulator**

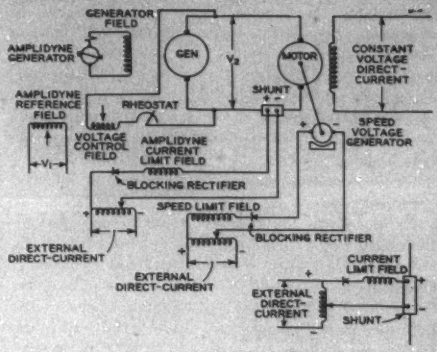


**Figure 11. Amplidyne-controlled adjustable-voltage (Ward-Leonard) drive with voltage control and speed and current limits**

to control remotely the static positions of machines as, for example, where the cutting heads on a boring mill have been adjusted automatically and accurately to 0.001 inch.

Another example of positioning is the application of the amplidyne in the process of paper or textile manufacturing which requires the straightening of moving rolls. In this process a reel shifting motor is used to shift the roll to the right or left as required. Projected onto the paper edge is a light beam which is reflected from the paper into a phototube whose output is proportional to the value of reflected light. The phototube is focused upon the moving edge of paper and any deviation of the edge varies the amount of reflected light and consequently varies the output of the phototube. An electronic device receives and amplifies the phototube output and supplies the increased power to the amplidyne fields. The amplidyne armature feeds the reel shifting motor and when the paper edge is in the proper position the control fields are of equal and opposite strength and consequently the amplidyne output is zero. However, any change in the position of the moving paper edge unbalances the amplidyne field circuit and the reel shifting motor then acts to correct the deviation.

An excellent combination is that of an amplidyne with vacuum tubes which are inherently fast in operation, are dependable, inexpensive, and easy to obtain. The low wattage required for amplidyne fields makes it possible to use high vacuum tubes as controlling or composing means. For example, a signal of 0.0001 watt is amplified by a tube to 0.01 watt and again by another tube to 1 watt. The power level of 1 watt can be applied to the field of a 10-kw amplidyne which is sufficient to excite a 2,500-kw generator and thus a total amplification of 25 billion to 1 is obtained. An illustration of

the vacuum tube and amplidyne combination is its use to control a flying shear which cuts a continuous sheet of steel into smaller lengths. It is very essential that these lengths of cut steel be consistent and also accurate within themselves. This accuracy had been maintained by mechanical ties holding the stand and shear motors in synchronism. When amplidyne control was placed in operation, the accuracy obtained was better than 1/4 of 1 per cent and was maintained even after the mechanical parts had begun to show signs of wear.

So far the amplidyne has been described as controlling d-c machines only but it also is useful to hold constant voltage and provide current limit on a-c generators. When used with synchronous motors, the amplidyne will hold constant power factor, or reactive kilovolt-amperes, or a combination of both, irrespective of load changes. In this case the synchronous motor field is excited from a conventional d-c exciter which, in turn, is excited separately from an amplidyne which acts to adjust the exciter field current. Three fields are used in the amplidyne. One functions simply to limit the range of exciter output voltage; the remaining two fields control the amplidyne output to hold the desired result on the synchronous motor. The benefits of this system, which are provided automatically by the amplidyne, are:

1. Increase in effective system capacity.
2. Improvement in voltage regulation.
3. Improvement in efficiency at light loads.
4. Increase of pullout torque at light loads.
5. Maintenance of normal voltage at no load and at heavy loads.

This description of the amplidyne generator, in an effort at clarity and brevity, has presented but a few fundamentals of its operation and applications. Nothing has been discussed in regard to suppression of oscillations generally always prevalent in systems with inherent high amplification and negative feed-back features, and although antihunt transformers and capacitors usually are provided with amplidyne controlled equipment the subject is beyond the scope of this article.

It can be seen, however, that the amplidyne is an extremely useful engineering tool. Its value was recognized immediately by the electrical industry although present knowledge indicates that its utilization has just begun. As for future prospects, it is expected that many new developments and applications, as yet still in the potential stage, will be made practicable through the use of the amplidyne.

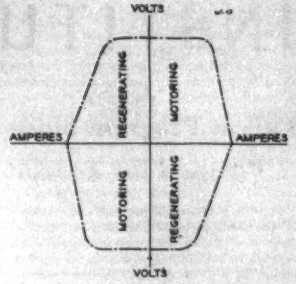


**Figure 13. Performance curve showing load limits without overshooting during stalled or plugging operations**

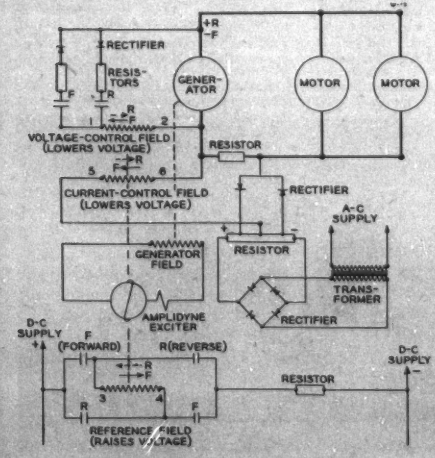


**Figure 12. Control for d-c generator feeding several d-c motors on an electric power shovel**

## Railroad Switch Deicers

A deicing or ice-prevention unit, comprised mainly of wrought iron pipe and an electrical heating element, has been devised by the Cleveland Railway Company, Cleveland, Ohio, to prevent track switches from freezing. Wrought iron was selected because of corrosive conditions encountered, especially from salt which is used to clear streets of ice and snow.

The unit runs parallel to the full length of the switch, buried about a foot deep. The deicer warms the area surrounding the switch so that snow is melted as it falls on the warm pavement, residual water is evaporated, and ice is prevented from forming.

The heaters are controlled by a switch located in a box set high on an adjacent line pole. During bad weather, the units are turned on and left in continuous operation. When prolonged periods of mild weather are indicated, the heaters are turned off. It requires approximately four hours to make the switches "ice-proof" after the heaters are put into operation from a cold start according to transit system engineers.

# INSTITUTE ACTIVITIES

## Fullest Program Since 1941

## Planned for Detroit Summer Convention

For the 61st annual summer convention of the AIEE, to be held in Detroit, Mich., June 24–28, 1946, the summer convention committee has planned a program of entertainment, inspection trips, and recreation complementing the excellent technical sessions, which should enhance the attraction of the convention as a vacation as well as a benefit professionally. Convention headquarters will be at the Hotel Statler located in the heart of downtown Detroit.

### TECHNICAL PAPERS

Many papers covering a wide variety of subjects in the field of electrical engineering will be presented in the technical sessions scheduled during the week of the convention. These will be listed in the June issue of *Electrical Engineering*, as well as in the announcement folder which will be mailed from AIEE headquarters. Among the sessions and conferences to be held, increased activity in the following fields will secure especial attention from many engineers.

### ELECTRONICS

Two technical sessions, a technical conference, and two joint conferences will be arranged under the auspices of the committee on electronics. One entire session will be devoted to papers on new or improved types of tubes, their performance characteristics, or their design features. The session has been planned to appeal to engineers with particular interest in tube design and manufacture and in ways in which these factors are influenced by the basic circuits or broad fields of application.

Electronics is finding a place in nearly every field of electrical engineering. Some of its applications represent new devices or methods that perform tasks previously impossible. Others represent ways of accomplishing an old result by a newer, better, or lower cost method in which electron tubes are employed. Papers on both types of application will appear throughout the various sessions as well as in a session devoted entirely to electronic applications.

In a conference on electronic power conversion a comprehensive report on inductive co-ordination aspects of rectifier installations will be presented, as well as a proposed standard on pool-cathode mercury-arc power converters. Another conference sponsored jointly with the committee on education will deal with the place of electronics in electrical engineering curriculums. Still another, to be held jointly with the committee on instruments and measurements, will concern electronic instruments.

### INSTRUMENTS AND CONTROL

A session on instruments and measurements will cover a wide range of subjects. Use of wartime techniques in peacetime applications will be emphasized. Papers on instruments and measurements related to power transformers, aircraft, instrument manufacture, telemetering, and power transmission are expected to be presented.

Because of wartime restrictions on the publication of technical material in the field of servomechanisms and control, the professional societies were forced to abandon normal activities in this field. Many of these restrictions now have been lifted, and a session on servomechanisms arranged jointly with the committee on industrial control devices will afford an opportunity for the Institute to bring forward for diacussion much of the accomplishments which were restricted during the war.

The newly established committee on industrial control devices will hold for the first time an entire session devoted to this subject. Papers discussing new advances in electric control devices and control circuits will be presented. One paper will report results of a series of tests on silicone varnish-treated magnet coils, and the probable advantages derived from the permissible increases in temperature with the use of this new kind of insulation will be discussed.

### SAFETY

In a session on safety one of the papers will discuss lethal electric currents and their accompanying physiological effects. Another paper will deal with methods for safeguarding operators and workers from the hazards which may accompany the use of X rays and gamma rays of radioactive material in industry. A third informal presentation will consider the shock hazards of low-voltage circuits.

### MANAGEMENT AND QUALITY CONTROL

A conference will be sponsored in this field by the AIEE subcommittee on applications to statistical methods. Several papers will be presented dealing with plant organization for quality control and meth-

**This Detroit skyline will greet arrivals at the summer convention, June 24-28, 1946**

ods of presenting results to management. Several outstanding executives also will discuss quality control from the point of view of management.

### GENERAL INFORMATION

A number of other sessions have been arranged tentatively in the fields of basic sciences, central stations, communication, transportation, electric machinery, and industry. In the central station field alone there will be sessions on power transmission, power cables, automatic or supervisory control of air switches, automatic switching of capacitor banks, hydroelectric systems, and excitation systems. In the field of transportation, papers will be presented which will deal with electrical applications to aircraft, railways, and installations on shipboard. As Detroit is one of the great industrial centers of the country, the problems of industry will be highlighted in all of the technical sessions and conferences. Two sessions will deal exclusively with problems in electric welding, and two others with industrial power applications.

### ENTERTAINMENT FEATURES

Excellent programs for both men and women have been planned by the hospitality and sports committees. Among the social events planned for the men are an American League twilight baseball game (Detroit versus Boston), the president's reception and cocktail hour, a smoker with dinner and entertainment, and a moonlight boat excursion.

An extensive program also is planned for the women. An informal get-together is planned for the first day, with the succeeding days holding numerous pleasant events. Among these is a sightseeing trip to Canada, which will go by way of Ambassador Bridge and return by way of the tunnel under the Detroit River. The trip will include a visit to some of the famous gardens of Windsor, a shopping tour, and tea at the Prince Edward Hotel in Windsor.

The following day at the Detroit Yacht Club on beautiful Belle Isle, a luncheon and fashion show will be held, with latest styles shown by models from some of Detroit's better shops. A dinner and keno party are planned for the following evening at the Book-Cadillac Hotel.

One of the exceptional entertainment features planned for the women is a visit to world-famous Greenfield Village. Among the innumerable attractions of the village are a group of homes of various periods from the early 17th through the 19th century, each complete with furnishings of its period, and various small shops and handicraft industries of early American days, including an apothecary shop, several early jewelry shops, and a tintype studio. Prominent in the village sights is the reconstructed original of the Menlo Park Laboratory and associated buildings, which were transported from New Jersey, complete even to the red soil typical of the original site. A luncheon at Dearborn Inn will follow the visit to the village, and in the afternoon a visit will be made to the Edison Institute Museum.

The sports committee has made arrangements with the Glen Oaks Golf Club for the use of the course during the first four days of the convention. A full golfing program is planned, including the Mershon Match Play Tournament, the Lee Tournament, which is a two-day, 36-hole medal play on a handicap, and at least one Kicker's Handicap Tournament. Anyone who desires to play without entering a tournament is welcome to do so. Transportation will be provided to and from the course.

Though no golf tournaments are planned for the women, the course privileges and transportation will be arranged for those who desire to play.

The past record has indicated very little interest in tennis, therefore, for this reason and because of the difficulty of obtaining suitable tennis courts, no tennis tournaments are planned.

### INSPECTION TRIPS

The various scheduled trips are so diversified as to satisfy every interest. One of the planned inspection trips with an unusually wide engineering coverage is the trip to the Chrysler Engineering Laboratories. Here, in a series of laboratories and test chambers, the Chrysler engineers check every detail of the parts which go to make up the finished automobile. Visitors will be conducted through the various testing laboratories to view the electric system tests, stress analysis, and fatigue tests, the checks made in the cold temperature chamber, which often has been pictured in advertisements, engine testing on latest type dynamometer units, and various materials testing and development, including rubber and plastics.

Also scheduled is a trip to the Ford Motor Company Rouge Plant at Dearborn, Mich., the world's largest industrial city. Grouped into a single unit covering 1,196 acres are blast furnaces, coke ovens, docks, assembly lines, machine and repair shops. Here are railroad and bus systems, the world's largest production foundry, a paper mill and a glass plant, power houses, and laboratories. More than 90,000 men and women are employed with a variety of skills and trades—seamstresses and sailors, carpenters and cooks, artists and accountants, metallurgists and machinists. Within the Rouge plant are more than 100 miles of railroad—one of the longest private railroads in the world. One and one-third miles of docks are needed to handle waterborne shipments, including upwards of 850,000 tons of ore and 2,078,000 tons of coal a season. Over 13,875,000 square feet of floor space, and 132 miles of conveyors are used in the Rouge Plant buildings. More than 538 million gallons of water are used in a day's operations, as well as enough gas for a city of 1,500,000 people. The ten open-hearth furnaces which provide steel for the rolling mill have a total capacity of over 1,800 tons per day.

Also prominent in the schedule of technical trips is the one to the Detroit plant of the United States Rubber Company on the Detroit River near scenic Belle Isle.

The principal product of this plant is automobile tires, and the visitor can view the various phases of manufacture from crude or synthetic rubber and cotton cords, rayon, or other fabrics all the way to the finished tire. Interesting manufacturing processes include the solutioning of cord or rayon fabric, the rubberizing of this fabric in calender trains, bias cutting and tire building operations, breaking down of crude or synthetic rubber in plasticators, compounding in Banbury mixers, and tuber and dual tuber operations forming tread and sidewall sections. Also evident is the continuous building of smaller size tires on "merry-go-rounds" and the mass vulcanizing of the daily quota, which present production schedules have set at approximately 30,000 units per day. Testing facilities allow the checking of any size tire, including landing tests for big airplane tires.

The recently completed expansion program added a number of modern electric drives, such as a synchronized rubber calender train, featuring a number of electronic and rotating regulator controls, new type rubber mills controlled by metal-clad vertical lift air circuit breakers, and new Banbury drives, including separately ventilated and cooled induction motors.

Of the scheduled inspection trips, the one which is planned to the Edison Institute Museum, although possibly ranking beneath the others in technical interest, will in all probability provide one of the highlights by virtue of the unusual group of exhibits which Mr. Henry Ford has spared no expense to collect. Under the three major divisions of agriculture, manufacture, and transportation, are shown the evolution and development of agricultural and household arts implements and equipment, replicas and collections of steam and electric power machinery from the earliest known types, numerous industries displays which utilize such power, and a complete exhibit of transportation equipment covering all forms of animal and powered carriers, and including development of bicycles, locomotives, automobiles, and airplanes. In addition to the major exhibits there are various handicraft shops and a museum collection of some 6,000 pieces of furniture, as well as musical instruments from earliest times to the present.

### HOTEL ACCOMMODATIONS

The hotels committee has been fortunate in securing block reservations at a group of hotels, the names and rates of which are listed in the accompanying table. All are within a short distance of headquarters.

The critical status of room reservations makes it imperative that reservations be made immediately to avoid disappointment. All requests for reservations should be addressed to AIEE Summer Convention Hotels Committee, 1005 Stroh Building, Detroit 26, Mich. It is also essential that the time of arrival be given. Double occupancy should be used wherever possible.

| Hotel | Rates | |
|---|---|---|
| | Single | Double |
| Book-Cadillac | $3.00 up | $5.00 up |
| Detroit Leland | $2.50 up | $4.00 up |
| Fort Shelby | $2.50 up | $4.00 up |
| Statler (headquarters) | $3.00 up | $4.50 up |
| Tuller | $2.00 up | $3.50 up |

# Mexico Section Participates in South West District Meeting

Re-establishing its program of District meetings and Student Branch conventions, the AIEE South West District met at the Plaza Hotel in San Antonio, Tex., April 16–18, 1946, the South Texas Section acting as host with the collaboration of the Houston Section. The total registration of 366 exceeded the committee's expectations by a substantial margin, and indicates a wide and healthy interest and participation in AIEE affairs in the South West. All Sections, Subsections, and Student Branches were represented, although there was insufficient time for the development of a complete Student program and full Student participation. Registration statistics are given in accompanying tabulations.

**Analysis of Registration at San Antonio**

| Classification | South Texas Section | District 7* | Other Districts | Totals |
|---|---|---|---|---|
| Members | 37 | 119 | 29 | 185 |
| Enrolled Students | 6 | 28 | | 34 |
| Men guests | 21 | 36 | 11 | 68 |
| Women guests | 15 | 56 | 8 | 79 |
| Totals | 79 | 239 | 48 | 366 |

* Outside South Texas.

The Mexico Section was an active participant in the San Antonio meeting, and gave it a very practical flavor of international co-operation. Those present included: Basil Nikiforoff (M '20) *past chairman*, Mexico Section, and chief electrical engineer, Mexico Light and Power Company, Mexico, Federal District, Mexico; Bernardo E. Arias (M '28) *past chairman*, Mexico Section, and chief electrical engineer, National Railways of Mexico; Federico A. Nava (A '42) *past chairman*, Mexico Section, and commercial manager, Westinghouse Electric Distributing Company, Mexico; Alejandro Paez Urquidi (A '44) *past chairman*, Mexico Section, and head of the rate department, Cia. Impulsora de Empresas Electricas, Mexico; Eduardo Luque Diaz, assistant manager in charge of Industria Electrica de Mexico, and professor of electrical engineering, University of Mexico; Luis Mascott (M '44) regional engineer in the Mexican territory for the Westinghouse Electric International Company and professor, University of Mexico; Antonio Baca (A '36) *secretary* of the Mexico Section and manager, elevator department, Westinghouse Electric Distributing Company; Manuel Diaz Montes de Oca (A '44) private dealer in electrical devices in the city of Mexico; Jaime Gonzalez Gil (A '31) electrical technical advisor to the government of the state of Coahuila, Mexico; Raoul Ramirez, manager air conditioning department, Westinghouse Electric Distributing Company; and Oscar R. Enriquez (A '42) general director of electricity under the orders of the Secretary of National Economy, and head of the hydroelectric division, Comision Nacional de Irrigacion.

With the assignment of Mexico as an integral part of the South West District, by action of the board of directors, May 22, 1945, and activation of the Beaumont Section, June 27, 1945, the District now is comprised of 11 Sections, 2 Subsections and 15 Branches. The Sections now include Mexico, New Mexico–West Texas, South Texas, Beaumont, Houston, Kansas City, North Texas, Oklahoma City, St. Louis, Tulsa, and Wichita. The Subsections include Albuquerque and Panhandle. Student Branches include University of Arkansas, Fayetteville; Kansas State College, Manhattan; University of Kansas, Lawrence; Missouri School of Mines and Metallurgy, Rolla; University of Missouri, Columbia; New Mexico State College, State College; University of New Mexico, Albuquerque; Oklahoma Agricultural and Mechanical College, Stillwater; University of Oklahoma, Norman; Rice Institute, Houston; Southern Methodist University, Dallas; Texas Agricultural and Mechanical College, College Station; Texas Technological College, Lubbock; University of Texas, Austin; and Washington University, St. Louis.

In addition to the four technical papers previously abstracted in *Electrical Engineering*, 18 other technical topics were presented mostly in the form of informal talks or discussions, at 6 technical sessions. Supplementing these were three Student papers at the Student session, a series of general addresses at the opening general session, and a conference on Institute activities.

### GENERAL SESSION

R. W. Warner, (F'39) AIEE vice-president for the South West District, presided at the opening general session, calling special attention to the participation of the Mexico Section and the presence of a large representation therefrom. O. R. Enriquez, chairman of the Mexico Section, responded with greetings from that Section, and a brief outline of its plans for the visit of President Wickenden, April 22.

Acting on behalf of Mayor G. B. Mauermann of San Antonio, Colonel W. B. Tuttle (M '30) chairman of the San Antonio Public Service Board, extended the city's official welcome and briefly outlined the evolutionary developments of electric power distribution and utilization in San Antonio. The San Antonio system is city-owned, having been taken over from the San Antonio Public Service Company in 1944.

Speaking on the assigned topic "The Institute Today," Secretary H. H. Henline presented a descriptive cross section of the Institute's organization and functional procedures, in accordance with the policies as established by the board of directors in the furtherance of the original and continuing basic objectives of the Institute: "The advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members." Mr. Henline traced the activities through which the Institute has grown through its 62 years of life, now comprising some 75 Sections, 24 Subsections, 75 technical groups, 125 Student Branches, and a total membership of 24,857 as of April 1, 1946. *Electrical Engineering* has a circulation currently in excess of 31,000. Now, 31 per cent of the total membership is in the Member and Fellow grades, as compared with 17 per cent in 1925. Mr. Henline touched briefly on some of the current problems and opportunities of the Institute, and laid especial emphasis upon the need for a greater flexibility in its technical organization and procedures, to enable it to meet the challenge of rapid growth and continuing changes in the ever-widening electrotechnical field.

"Tomorrow's Engineering Developments" were described by M. W. Smith (F '42) vice-president in charge of engineering for the Westinghouse Electric Corporation (see pages 197–201 of this issue).

Discussing "Engineering for Postwar Problems," A. S. Langsdorf (F '12) dean of engineering and architecture, Washington University, St. Louis, Mo., bluntly challenged the efficacy or desirability of some of the current trends in education, and called upon engineers in the teaching profession as well as those in commercial and industrial practice to give attention to the matter so that education could better serve its objective of fitting its recipients to take a constructive and productive place in a complex and highly technological civilization. Dean Langsdorf criticized the growing philosophy in American public schools that no student should fail; that all should "pass" regardless of capabilities or aptitudes. He called for more teaching of grammar in grammar schools, and more teaching of practical English, composition, and other such fundamentals in high schools. He called also for a sifting of college technical curricula, to eliminate the many existing duplications and repetitions, thus providing more time and opportunity for the broadening of the coverage of such curricula that is necessary in his opinion to fit engineering and other technical students to meet the requirements of rapidly expanding technology. He took special issue with the

**Comparison of South West District Meeting Attendance**

| | | |
|---|---|---|
| 1946 | San Antonio, Tex. | 366 |
| 1943 | Kansas City, Mo. | 339 |
| 1941 | St. Louis, Mo. | 553 |
| 1939 | Houston, Tex. | 535 |
| 1936 | Dallas, Tex. | 533 |
| 1935 | Oklahoma City, Okla. | 571 |
| 1931 | Kansas City, Mo. | 411 |
| 1929 | Dallas, Tex. | 541 |
| 1928 | St. Louis, Mo. | 500 |
| 1927 | Kansas City, Mo. | 225 |

recurrent proposal further to dilute current engineering curricula by the substitution of 20 per cent of selected "cultural" subjects. Dean Langsdorf cited the cultural education of an engineer as a continuing process applicable differently to different individuals, and tossed the responsibility for such continuing education on the national engineering societies rather than on the colleges. Dean Langsdorf's address is scheduled for publication in an early issue of *Electrical Engineering*.

President Wickenden, responding to the chairman's request for remarks, reminded his listeners that "like it or not, the engineer and scientist of today finds himself very much at the center of the complex and rapidly moving problems of an atomic age." As an indication of the factors underlying current legislative trends, he pointed out that 125 years ago some 75 per cent of the people of the United States earned their living from their own property, whereas now only something like 15 per cent earn their living from their own property. Thus, has come about the trend from laws protecting property to the modern trend of legislation establishing labor rights, wage levels, and other aspects of social security. As for national wealth, Doctor Wickenden pointed out that the days of "windfall wealth" are approaching an end—the days of discovering and exploiting great mineral and oil deposits, for example. Doctor Wickenden stated that "tomorrow's prospecting or new developments of importance to national wealth will be done in the research laboratories, not in the great open spaces." He also stated that "the time has gone by when the engineer and scientist can consider that he has discharged his obligation to society by just the doing of an honest day's work on an assigned technical job; he must be imaginative and forward-looking; he must create."

### EXECUTIVE COMMITTEES MEET

The District executive committee held a luncheon meeting Friday noon, April 18. Action on the next District meeting and Student Branch convention was held in abeyance, and referred to the 1946–47 committee.

The formation of technical groups within the various Sections, as a means of expanding the range of subject matter and the opportunity for individual participation in line with local conditions and interests, has been one of the most active projects of the District executive committee during the past year. The St. Louis Section reported that it had activated discussion groups on industrial power and on electronics, and planned to activate three more this next year. Houston reported two, one on electronics and one on industrial applications, and reported that more new membership applications had resulted from extension of technical group activities than from any other single source of activity. Tulsa reported discussion groups on electronics and on corrosion testing, with plans for two or three more next year. Kansas City reported three technical groups, one on professional matters, one on electronics, and one on industrial practices; some of these groups meet every two weeks, the interest is so active. Oklahoma City reported six: frequency modulation, electronics, transmission and distribution, a-c circuit analysis, rural electrification, and nuclear physics, with attendance averaging 10 or better. New Mexico–West Texas reported discussion groups on power and on electronics, with attendance ranging from 15 to 20; and also reported formation of the Albuquerque Subsection, with an active response from members in that territory. Wichita currently is surveying the various industries to ascertain subjects of interest. Beaumont, a brand-new Section, developed as an offshoot of the Houston Section, is actively planning technical groups. Mexico Section reported that it is planning to establish Subsections in Monterey, Chihuahua, and Saltillo. South Texas reported no technical groups as yet.

Student counselors and chairmen of Student Branches held a joint luncheon meeting Wednesday, April 17. Professor M. C. Hughes (F '43) head of the electrical engineering department, Agricultural and Mechanical College of Texas, and chairman of student counselors for the South West District presided. E. W. O'Brien (M '37) of Atlanta, Ga., chairman of the AIEE committee on Student Branches, was in attendance. He reported briefly on the plans for joint Student Branch organizations where such are advantageous, and laid special emphasis upon the reactivation of District Student Branch conferences, either separately or in connection with District meetings.

Action was taken by the counselors calling for definite plans to be made beginning at once for a Student conference next year, to be held in connection with the District meeting if a District meeting is held, and to be held separately otherwise. Action also was taken electing officers of the District Student Branch counselors for the administrative year 1946–47 as follows: *District Student Branch chairman*, Professor C. L. Farrar (M '40) of the University of Oklahoma; *District counselor secretary*, M. V. McEnany (A '43) of Rice Institute.

### STUDENT TECHNICAL SESSION

A student technical session, under the chairmanship of Professor W. F. Helwig, (M '31) counselor of the Student Branch at Texas Technological College, attracted an attendance of some 65 persons including many engineers in addition to the students. Four student papers were presented, as follows:

1. "A New Tool for Frequency Modulation," **Vernon Holman**, Kansas State College Branch.
2. "Principles of Grounding," **G. D. Spradling**, University of Missouri Branch.
3. "Residential Heating by Electricity," **C. D. Montgomery**, Southern Methodist University Branch.
4. "Applications of Selsyn Equipment," **Paul L. Harton**, Southern Methodist University Branch.

### ENTERTAINMENT

A general trip to Randolph Field, the United States Army Air Forces "West Point of the air," some 17 miles north of San Antonio, was one of the two major general entertainment features for men and women. About 120 persons made this trip. The biggest feature on the entertainment program was the banquet held at the Plaza Hotel, Wednesday evening, April 17, and attended by 308 persons, the capacity of the ballroom. A musical show featuring Mexican music, singers, and dancers, won the noisy approval of the guests. President Wickenden brought the affair to a close with a brief, entertaining, and stimulating address.

A full program of entertainment features for women guests included, in addition to the features mentioned in the foregoing paragraph, a sight-seeing tour to the many points of historic and scenic interest in San Antonio and environs, a dinner at the San Antonio country club, and a bridge party at the Plaza Hotel. The women's dinner at the country club paralleled the stag smoker and informal social hour at the Plaza Hotel the evening of the first day.

### Future AIEE Meetings

**Summer Convention**
Detroit, Mich., June 24–28, 1946

**Pacific Coast Convention**
Seattle, Wash., August 27–30, 1946

**Great Lakes District Meeting**
Fort Wayne, Ind., September 25–27, 1946

## Conference on Institute Activities Held at South West District Meeting

In furtherance of its current program of investigating AIEE affairs for the purpose of determining ways and means of improving them, the AIEE committee on planning and co-ordination sponsored a conference at San Antonio during the District meeting. Chairman of the conference session, and representative of the committee, was T. G. LeClair, (F' 40) chairman of the professional activities subcommittee.

As the basis for discussion, reprints of the subcommittee's progress report entitled "Organization of the Engineering Profession" (*EE, Apr '46, pp 169–73*) had been widely distributed the day before the meeting; also, current progress reports prepared by the professional activities subcommittee and by the technical activities subcommittee of the committee on planning and co-ordination (*pp 222–4*) were

read to the conference group. To facilitate the committee's further study, questionnaires were distributed for execution by those present.

Representatives of the various Sections and other groups in the District were called upon for comment and discussion, and in addition to this there was some discussion and questioning from the floor. The discussion may be summarized briefly as indicating clearly a desire for (a) continuation and expansion of the Institute's program of technical activities; (b) appropriate active parallel participation in the so-called "professional," or nontechnical, fields affecting and affected by engineers, by appropriate collaboration with other engineering societies. In terms of the "plans" of the subcommittee's report, "Plan B" was favored by most commentators, but strong support also was expressed for appropriate utilization of the local-council idea indicated in "Plan C." The question of the registration and licensing of professional engineers was touched upon in some way or other by most of the commentators.

In accordance with the program as previously arranged, Elgin B. Robertson (F '45) of Dallas, past president of the Texas Society of Professional Engineers, presented a summarizing discussion to conclude the conference. Mr. Robertson, long active in the National Society of Professional Engineers, also has been active over a great many years in AIEE affairs, and currently is District vice-chairman of the AIEE membership committee.

Mr. Robertson, touching upon the various ideas brought forth in the conference, dwelt particularly upon the relationship between the field of engineering activity represented by the National Society of Professional Engineers and the fields of activity represented by the AIEE and other national engineering and technical societies. On the basis of his own varied experience and active participation, he pointed out strongly that both phases of engineering activity are essential, and that neither should be promoted or developed at the expense of the other. In Mr. Robertson's stated opinions, it is not only possible but logical and desirable that an individual engineer should divide his activities between his technical societies and his professional society, in accordance with his interests.

In defense of diverse technical societies, Mr. Robertson asserted that in his opinion no single technical society can be all inclusive and function adequately in the several technical fields. Conversely, however, he stated his firm conviction that a professional society such as the National Society of Professional Engineers could perform successfully on an all-inclusive basis embracing the general considerations which are common to all engineers regardless of technical specialty. Identifying the foregoing comments as representing his point of view as past president of the Texas Society of Professional Engineers, Mr. Robertson stated that for his comments as an AIEE member and as District vice-chairman of the membership committee, he would read a letter just received from Lawrence F. Howard, chairman of the AIEE membership committee, which represented his views, also. The essential substance of Mr. Howard's communication is given in the following paragraphs.

"... it is the job of the membership committee to be ready at all times to assist in acquainting qualified persons with the advantages of becoming a member of the American Institute of Electrical Engineers. These advantages are many and stem from the fact that the AIEE is *the* organization representing the electrical engineering profession which has membership in all parts of the Western Hemisphere and abroad. The degree of accomplishment of the committee is measured particularly in the last two years by an increase in membership from about 21,400 to an expected total of 25,000 or more in May of this year. The strength of the Institute is emphasized further by the fact that 2,500 members who had an 'inactive' status during the war period are now voluntarily requesting active status again as their war service terminates. Some 600 have been reinstated to active membership in the last few months and the requests are coming in rapidly from others each day. Another significant fact is that which pertains to delinquents. This year the number of delinquents (those one year in arrears in dues) is approximately one-half of the number one year ago. It is the lowest for a great many years in the history of the Institute. It is significant also that the Student membership as of January 1946 was approximately 4,000 and that this number was only 43 smaller than in January 1945. The number of members-for-life are 1,170, of which number 113 still choose to pay dues. There are 51 Life Members. The number of applications continues to run ten per cent ahead of last year. For the first time there are now more members of Member grade than Associates of more than six years standing.

"There seems to be no sign at present which indicates the Institute should not continue to grow in numbers and influence correspondingly. It is the largest by far of the four Founder Societies. It is unique in its field of opportunity to the individual electrical engineer and for service to humanity by virtue of the fact that the development in the future will be so closely allied with electronic applications.

"Under such conditions and considering the peculiarities of the present economic situation, it is only natural that questions relative to the organization of the Institute should arise. Certainly, however, no disintegration or crumbling of the Institute is in view as a result. On the contrary, it seems quite clear that an organization which has served so faithfully and well in the past is in the best position to meet the present and future challenge of the electrical engineering field.

"Any modifications other than possibly the establishment of new committees and the broadening of the responsibilities of the present committees are not clear as yet from a membership committee activity standpoint. Certainly our officers and the board of directors are aware of any matters in this connection and are guiding the course of the Institute ably with the benefit of constructive suggestions from the Sections. For example, steps along those lines have been taken and the results of a committee study on the question of 'collective bargaining' have been made available. According to the data at hand, more information on that subject is to be sent to each member of the Institute. The activities of other committees should develop some other constructive thoughts. There appears as yet no need for the membership committee to change its policy or to lessen its enthusiasm in carrying the benefits of membership in the Institute to all qualified persons. . . .

"Membership work cuts across every activity of the Institute; or, to put it in another way, the activities of the Institute's Sections can cause persons to be enthused toward becoming members or materially dampen any enthusiasm present. The membership committee and members of the Institute, therefore, can be instrumental in obtaining new members but the membership committee alone cannot keep them interested if other activities of the Institute do not give the members attractive programs and opportunities to keep the interest alive. The Sections committee of the Institute has realized this fact and is more than usually active in stimulating the functioning of the Sections.

"The Institute is an organization of individuals working toward the advancement of the theory and practice of electrical engineering and the allied arts and sciences, the maintenance of a high professional standing among its members and the development of the individual engineer. . . ."

The various comments and questionnaires collected from the San Antonio conference will be studied by the committee on planning and co-ordination, along with similar information which the committee is planning to gather at other similar meetings and conferences.

## Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Hotel Statler, Detroit, Mich., at 10 a.m. Monday, June 26, 1946.

At this meeting, the annual report of the board of directors and the report of the committee of tellers on the ballot cast for the election of officers will be presented. The Lamme Medal will be presented to David C. Prince (F '26), and awards of Institute prizes will be announced.

Such other business, if any, as properly may come before the annual meeting may be considered.

(*Signed*) H. H. HENLINE
*Secretary*

# AIEE Endorses Model Law for Registration of Engineers

At its January meeting the AIEE board of directors adopted a resolution declaring "that the AIEE recognizes the registration of engineers as a continuing practice and the 'Model Law for the Registration of Professional Engineers and Land Surveyors' as adopted in 1943 and amended in 1945, as the widely accepted basis of its administration, and that the Institute endorses these procedures as well established." In line with this endorsement, the board approved a recommendation that the special AIEE committee on registration of engineers be replaced by a standing committee.

The first such model law indorsed by a number of engineering societies was drafted in 1932. Revisions were incorporated in 1937 and 1943. Organizations which have endorsed this latest amended law are: the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Association of Engineers, the American Institute of Consulting Engineers, the National Society of Professional Engineers, the National Council of State Boards of Engineering Examiners, the American Society of Heating and Ventilating Engineers, and the American Institute of Mining and Metallurgical Engineers. The text of the law as revised in 1943 follows, with the amendments agreed upon in August 1945 appearing in italic type.

## Text of Model Law

### TITLE

*An Act to regulate the practices of engineering and land surveying; providing for the registration of qualified persons as professional engineers and land surveyors, and providing for the certification of engineers-in-training; defining the terms "engineer," "professional engineer," "engineer-in-training," "practice of engineering," "land surveyor" and "practice of land surveying"; creating a state board of registration for professional engineers and land surveyors and providing for the appointment of its members; fixing the term of the Board and defining its powers and duties; setting forth the minimum qualifications and other requirements for registration; establishing fees with expiration and renewal requirements; imposing certain duties upon the State and political subdivisions thereof in connection with public work, and providing for the enforcement of this Act and penalties for its violation.*

### GENERAL PROVISIONS

*Section 1.* Be it enacted by the General Assembly of the State of ..... that in order to safeguard life, health, and property, and to promote the public welfare, any person in either public or private capacity practicing or offering to practice engineering or land surveying,[1] shall hereafter be required to submit evidence that he is qualified so to practice and shall be registered as hereinafter provided; and it shall be unlawful for any person to practice or to offer to practice in this State, engineering or land surveying, as defined in the provisions of this Act, or to use in connection with his name or otherwise assume, use, or advertise any title or description tending to convey the impression that he is a professional engineer or a land surveyor, unless such person has been duly registered under the provisions of this Act.

[1] Land surveying does not involve matters that would ordinarily jeopardise life and health, but property rights are vitally affected by land surveying, and many states have deemed it essential to place restrictions and safeguards about its practice. Surveying is a function of engineering, but land surveying deals with land measurements involving property rights.

### DEFINITION

*Section 2.* **The term engineer** as used in this Act shall mean a professional engineer as hereinafter defined.

**The term "professional engineer"** *within the meaning and intent of this Act shall mean a person who, by reason of his special knowledge of the mathematical and physical sciences and the principles and methods of engineering analysis and design, acquired by professional education and practical experience, is qualified to practice engineering as hereinafter defined, as attested by his legal registration as a professional engineer.*

**The term engineer-in-training** *as used in this Act shall mean a candidate for registration as a professional engineer who is a graduate in an approved engineering curriculum of four years or more from a school or college approved by the Board as of satisfactory standing, or who has had four years or more of experience in engineering work of a character satisfactory to the Board; and who, in addition, has successfully passed the examination in the fundamental engineering subjects prior to completion of the requisite years of experience in engineering work, as provided in Section 14 of this Act, and who shall have received from the Board, as hereinafter defined, a certificate stating that he has successfully passed this portion of the professional examinations.*

**The term engineering** as used in this Act shall mean engineering as hereinafter defined.

**The term "practice of engineering"** *within the meaning and intent of this Act shall mean any professional service or creative work requiring engineering education, training, and experience and the application of special knowledge of the mathematical, physical and engineering sciences to such professional services or creative work as consultation, investigation, evaluation, planning, design, and supervision of construction for the purpose of assuring compliance with specifications and design, in connection with any public or private utilities, structures, buildings, machines, equipment, processes, works or projects.*

*A person shall be construed to practice or offer to practice engineering, within the meaning and intent of this Act, who practices any branch of the profession of engineering; or who, by verbal claim, sign, advertisement, letterhead, card, or in any other way represents himself to be a professional engineer, or through the use of some other title implies that he is a professional engineer; or who holds himself out as able to perform, or who does perform, any engineering service or work or any other professional service designated by the practitioner or recognized by educational authorities as engineering.*

**The practice of engineering shall not include** the work ordinarily performed by persons who operate or maintain machinery or equipment.

**The term land surveyor** as used in this Act shall mean a person who engages in the practice of land surveying as hereinafter defined.

**The practice of land surveying** within the meaning and intent of this Act includes surveying of areas for their correct determination and description and for conveyancing, or for the establishment or re-establishment of land boundaries and the plotting of lands and subdivisions thereof.

**The term "Board"** as used in this Act shall mean the State Board of Registration for Professional Engineers and Land Surveyors, provided for by this Act.

### BOARD

*Section 3.* A State Board of Registration for Professional Engineers and Land Surveyors is hereby created whose duty it shall be to administer the provisions of this Act. The Board shall consist of five professional engineers, who shall be appointed by the Governor from among nominees recommended by the representative engineering societies in the State and shall have the qualifications required by Section 4. The members of the first Board shall be appointed within ninety days after the passage of this Act, to serve for the following terms: One member for one year, one member for two years, one member for three years, one member for four years, and one member for five years, from the date of their appointment, or until their successors are duly appointed and qualified. Every member of the Board shall receive a certificate of his appointment from the Governor and before beginning his term of office shall file with the Secretary of State his written oath or affirmation for the faithful discharge of his official duty. Each member of the Board first appointed hereunder shall receive a certificate of registration under this Act from said Board. On the expiration of the term of any member, the Governor shall in the manner hereinbefore provided appoint for a term of five years a registered professional engineer, having the qualifications required by Section 4, to take the place of the member whose term on said Board is about to expire. Each member shall hold office until the expiration of the term for which such member is appointed or until a successor shall have been duly appointed and shall have qualified.

*Section 4.* Each member of the Board shall be a citizen of the United States and a resident of this State, and shall have been engaged in the practice of the profession of engineering for at least twelve years, and shall have been in responsible charge of important engineering work for at least five years. Responsible charge of engineering teaching may be construed as responsible charge of important engineering work.

*Section 5.* Each member of the Board shall receive the sum of ..... dollars ($....) per diem when actually attending to the work of the Board or any of its committees and for the time spent in necessary travel; and, in addition thereto, shall be reimbursed for all actual traveling, incidental, and clerical expenses necessarily incurred in carrying out the provisions of this Act.[2]

*Section 6.* The Governor may remove any member of the Board for misconduct, incompetency, neglect of duty, or for any other sufficient cause. Vacancies in the membership of the Board shall be filled for the unexpired term by appointment by the Governor as provided in Section 3.

*Section 7.* The Board shall hold a meeting within thirty days after its members are first appointed, and thereafter shall hold at least..... regular meetings each year. Special meetings shall be held at such time as the by-laws of the Board may provide. Notice of all meetings shall be given in such manner as the by-laws may provide. The Board shall elect or appoint annually the following officers:[3] A Chairman, a Vice-Chairman, and a Secretary. A Quorum of the Board shall consist of not less than three members.

*Section 8.* The Board shall have the power to adopt and amend all by-laws and rules of procedure, not inconsistent with the Constitution and Laws of this State, which may be reasonably necessary for the proper performance of its duties and the regulations of the proceedings before it. The Board shall adopt and have an official seal.

In carrying into effect the provisions of this Act, the Board, under the hand of its Chairman and the seal of the Board, may subpoena witnesses and compel their attendance, and also may require the production of books, papers, documents, etc., in a case involving the revocation of registration or practicing or offering to practice without registration. Any member of the Board may administer oaths or affirmations to witnesses appearing before the Board. If any person shall refuse to obey any subpoena so issued, or shall refuse to testify or produce any books, papers, or documents, the Board may present a petition to such authority[4] as may have jurisdiction, setting forth the facts, and thereupon such authority shall, in a proper case, issue its subpoena to such person, requiring his attendance before such authority and there to testify or to produce such books, papers, and documents, as may be deemed necessary and pertinent by the Board. Any person failing or refusing to obey the subpoena or order of the said authority may be proceeded against in the same manner as for refusal to obey any other subpoena or order of the authority.

### RECEIPTS AND DISBURSEMENTS

*Section 9.* The Secretary of the Board shall receive and account for all moneys derived under the provisions of this Act, and shall pay the same monthly to the

[2] The per diem allowance of members of the Board is not indicated nor is it intended to be fixed as a commensurate compensation for the services to be rendered. High grade professional men are expected to serve as a matter of good citizenship.

[3] It is deemed advisable to have a member of the Board fill the office of Secretary, but as provided in Section 9, the Board may appoint an assistant secretary, executive secretary, treasurer, or other officer, not a member of the Board, to whom clerical and administrative duties may be assigned.

[4] "Authority" may be replaced by the designation of the proper Court or other suitable judicial unit.

State Treasurer, who shall keep such moneys in a separate fund to be known as the "Professional Engineers' Fund." Such fund shall be kept separate and apart from all other moneys in the Treasury, and shall be paid out only by .....[9] All moneys in the "Professional Engineers' Fund" are hereby specifically appropriated for the use of the Board. The Secretary of the Board shall give a surety bond to the State in such sum as the Board may determine. The premium on said bond shall be regarded as a proper and necessary expense of the Board, and shall be paid out of the "Professional Engineers' Fund." The Secretary of the Board shall receive such salary as the Board shall determine in addition to the compensation and expenses provided for in Section 5. The Board may employ such clerical or other assistants as are necessary for the proper performance of its work, and may make expenditures of this fund for any purpose which in the opinion of the Board is reasonably necessary for the proper performance of its duties under this Act, including the expenses of the Board's delegates to annual conventions of, and membership dues to, the National Council of State Boards of Engineering Examiners. Under no circumstances shall the total amount of warrants issued by .....[10] be in payment of the expenses and compensation provided for in this Act exceed the amount of the examination and registration fees collected as herein provided.

## RECORDS AND REPORTS

*Section 10.* The Board shall keep a record of its proceedings and a register of all applications for registration, which register shall show (*a*) the name, age, and residence of each applicant; (*b*) the date of the application; (*c*) the place of business of such applicant; (*d*) his educational and other qualifications; (*e*) whether or not an examination was required; (*f*) whether the applicant was rejected; (*g*) whether a certificate of registration was granted; (*h*) the date of the action of the Board; and (*i*) such other information as may be deemed necessary by the Board.

The records of the Board shall be *prima facie* evidence of the proceedings of the Board set forth therein, and a transcript thereof, duly certified by the Secretary of the Board under seal, shall be admissible in evidence with the same force and effect as if the original were produced.

Annually, as of ..... [insert date], the Board shall submit to the Governor a report of its transactions of the preceding year, and shall also transmit to him a complete statement of the receipts and expenditures of the Board, attested by affidavits of its Chairman and its Secretary.

## ROSTER

*Section 11.* A roster showing the names and places of business of all registered professional engineers and all registered land surveyors shall be published by the Secretary of the Board during the month of ..... of each year. Copies of this roster shall be mailed to each person so registered, placed on file with the Secretary of State, and furnished to the public upon request.[11]

## GENERAL REQUIREMENTS FOR REGISTRATION

*Section 12. The following shall be considered as minimum evidence satisfactory to the Board that the applicant is qualified for registration as a professional engineer, engineer-in-training, or land surveyor, respectively; to wit:*

(1) As a professional engineer:

**a. Graduation Plus Experience.** Graduation in an approved engineering curriculum of four years or more from a school or college approved by the Board as of satisfactory standing; and a specific record of an additional four years or more of experience in engineering work of a character satisfactory to the Board, and indicating that the applicant is competent to practice engineering (in counting years of experience, the Board at its discretion may give credit, not in excess of one year, for satisfactory graduate study in engineering), provided that in a case where the evidence presented in the application does not appear to the Board conclusive nor warranting the issuing of a certificate of registration, the applicant may be required to present further evidence for the consideration of the Board, and may also be required to pass an oral or written examination, or both, as the Board may determine; or

**b. Experience Plus Examination.** *A specific record of eight years or more of experience in engineering work of a character satisfactory to the Board and indicating that the applicant is competent to practice engineering; and successfully passing a written or written and oral, examination designed to show knowledge and skill approximating that attained through graduation in an approved four-year engineering curriculum; or*

**c. Engineers of Long Established Practice.** A specific record of twelve years or more of lawful practice in engineering work of a character satisfactory to the Board and indicating that the applicant is qualified to design or to supervise construction of engineering works and provided applicant is not less than thirty-five years of age.

(2) As an engineer-in-training:

**a. Graduation Plus Examination.** *Graduation in an accredited engineering curriculum of four scholastic years or more from a school or college approved by the Board as of satisfactory standing, and successfully passing a written examination in the basic engineering subjects; or*

**b. Experience Plus Examination.** *A specific record of four years or more of experience in engineering work of a character satisfactory to the Board; and successfully passing the Board's written examination in the basic engineering subjects.*

**a. Graduation Plus Experience.** Graduation from a school or college approved by the Board as of satisfactory standing, including the completion of an approved course in surveying; and an additional two years or more of experience in land surveying work of a character satisfactory to the Board and indicating that the applicant is competent to practice land surveying; or

**b. Experience Plus Examination.** *A specific record of six years or more of experience in land surveying work of a character satisfactory to the Board and indicating that the applicant is competent to practice land surveying; and successfully passing a written, or written and oral, examination in surveying prescribed by the Board; or*

**c. Long Established Practice.** A specific record of ten years or more of lawful practice in land surveying work of a character satisfactory to the Board and provided applicant is not less than thirty years of age.

## CHARACTER

*No person shall be eligible for registration as a professional engineer, engineer-in-training, or land surveyor, who is not of good character and reputation.*

## TEACHING CREDITS

In considering the qualifications of applicants, engineering teaching may be construed as engineering experience.

## EDUCATION CREDITS

The satisfactory completion of each year of an approved curriculum in engineering in a school or college approved by the Board as of satisfactory standing, without graduation, shall be considered as equivalent to a year of experience in Section 12 (1)*b* and (2)*b*. Graduation in a curriculum other than engineering from a college or university of recognized standing may be considered as equivalent to two years of experience in Section 12 (1)*b* and (2)*b*; provided, however, that no applicant shall receive credit for more than four years of experience because of undergraduate educational qualifications.

## WORK AS CONTRACTOR

The mere execution, as a contractor, of work designed by a professional engineer, or the supervision of the construction of such work as a foreman or superintendent shall not be deemed to be practiced in engineering.

## NON-PRACTICING APPLICANTS

Any person having the necessary qualifications prescribed in this Act to entitle him to registration shall be eligible for such registration although he may not be practicing his profession at the time of making his application.

## APPLICATIONS AND REGISTRATION FEES

*Section 13.* Applications for registration shall be on forms prescribed and furnished by the Board, shall contain statements made under oath, showing the applicant's education and detail summary of his technical work, and shall contain not less than five references, of whom three or more shall be engineers having personal knowledge of his engineering experience.

The registration fee for professional engineers shall be twenty-five dollars ($25.00), fifteen dollars ($15.00) of which shall accompany application, the remaining ten dollars ($10.00) to be paid upon issuance of certificate. *The fee for engineer-in-training shall be ten dollars ($10.00), which shall accompany the application and shall include the cost of examination and issuance of certificate. When registration as a professional engineer is completed by an engineer-in-training, an additional fee of fifteen dollars ($15.00) shall be paid before issuance of certificate as professional engineer.* When a certificate of qualification issued by the National Bureau of Engineering Registration is accepted as evidence of qualification, the total fee for registration as professional engineer shall be ten dollars ($10.00).

The registration fee for land surveyors shall be fifteen dollars ($15.00), which shall accompany application.

Should the Board deny the issuance of a certificate of registration to any applicant the initial fee deposited shall be retained as an application fee.[12]

## EXAMINATIONS

*Section 14.* When oral or written examinations are required, they shall be held at such time and place as the Board shall determine. If examinations are required on fundamental engineering subjects (such as are ordinarily given in college curricula) the applicant shall be permitted to take this part of the professional examination prior to his completion of the requisite years of experience in engineering work, and satisfactory passage of this portion of the professional examination by the applicant shall constitute a credit for a period of ten years. The Board shall issue to each applicant upon successfully passing the examination in fundamental engineering subjects a certificate stating that he has passed the examination and that his name has been recorded as an engineer-in-training.

The scope of the examinations and the methods of procedure shall be prescribed by the Board with special reference to the applicant's ability to design and supervise engineering works so as to insure the safety of life, health, and property. Examinations shall be given for the purpose of determining the qualifications of applicants for registration separately in engineering and in land surveying. A candidate failing on examination may apply for re-examination at the expiration of six months and will be re-examined without payment of additional fee. Subsequent examination will be granted upon payment of a fee to be determined by the Board.

## CERTIFICATES—SEALS

*Section 15.* The Board shall issue a certificate of registration upon payment of registration fee as provided for in this Act, to any applicant who, in the opinion of the Board, has satisfactorily met all the requirements of this Act. In case of a registered engineer, the certificate shall authorize the practice of "engineering," and in the case of a registered land surveyor, the certificate shall authorize the practice of "land surveying."

*In case of engineer-in-training, the certificate shall state that the applicant has successfully passed the examination in fundamental engineering subjects required by the Board and has been enrolled as an "engineer-in-training."* Certificates of registration shall show the full name of the registrant, shall have a serial number, and shall be signed by the Chairman and the Secretary of the Board under seal of the Board.

The issuance of a certificate of registration by this Board shall be *prima facie* evidence that the person named therein is entitled to all the rights and privileges of a registered professional engineer, or of a regis-

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[9] Insert title of proper State official, and method of authentication and payment.

[10] Insert title of proper State official.

[11] It is desirable that copies of the annual rosters be made available to county authorities and to the authorities of the principal cities in the State, for record.

[12] The standard of qualification is set high for two reasons: The public welfare will be better promoted by maturer competency; and the prestige attaching to the term "Registered" will be more significant for the professional men themselves. In requiring the younger, less experienced men to serve somewhat longer as assistants or understudies to older men, no hardship is imposed which will not be compensated by the fuller return in recognition when registration is achieved.

[13] It may be advisable in some cases to grant the Board authority, with the approval of the Governor, to increase or decrease the fees for certificates and renewals within certain defined limits, in order to keep the Board self-sustaining, and to meet any objection raised that the passage of the Registration Act would tend to increase taxes.

tered land surveyor, while the said certificate remains unrevoked or unexpired.

Each registrant hereunder shall upon registration obtain a seal of the design authorized by the Board, bearing the registrant's name and the legend, "Registered Professional Engineer," or "Registered Land Surveyor." Plans, specifications, plats, and reports prepared by a registrant shall be stamped with the said seal when filed with public authorities, during the life of the registrant's certificate, but it shall be unlawful for any one to stamp or seal any documents with said seal after the certificate of the registrant named thereon has expired or has been revoked, unless said certificate shall have been renewed or reissued.[18]

## EXPIRATIONS AND RENEWALS

*Section 16.* Certificates of registration shall expire on the last day of the month of ..... following their issuance of renewal and shall become invalid on that date unless renewed. It shall be the duty of the Secretary of the Board to notify every person registered under this Act, of the date of the expiration of his certificate and the amount of the fee that shall be required for its renewal for one year; such notice shall be mailed at least one month in advance of the date of the expiration of said certificate. Renewal may be effected at any time during the month of ..... by the payment of a fee of ..... dollars ($.....).[18] The failure on the part of any registrant to renew his certificate annually in the month of ..... as required above shall not deprive such person of the right of renewal, but the fee to be paid for the renewal of a certificate after the month of ..... shall be increased ten per cent for each month or fraction of a month that payment of renewal is delayed; provided, however, that the maximum fee for delayed renewal shall not exceed twice the normal renewal fee.

## PRACTITIONERS AT TIME ACT BECAME EFFECTIVE

*Section 17.* At any time within one year after this Act becomes effective, upon due application therefor and the payment of the registration fee of fifteen dollars ($15.00) for professional engineers, or ten dollars ($10.00) for land surveyors, the Board shall issue a certificate of registration, without oral or written examination, to any professional engineer or land surveyor who shall submit evidence under oath satisfactory to the Board that he is of good character, has been a resident of the State of ..... for at least one year immediately preceding the date of his application, and was practicing engineering if an engineer, or land surveying if a surveyor, at the time this Act became effective, and has performed work of a character satisfactory to the Board.

After this Act shall have been in effect one year, the Board shall issue certificates of registration only as provided for in Section 12 or Section 19 thereof.

## PUBLIC WORK

*Section 18.* After the first day of ....., one thousand nine hundred and ....., it shall be unlawful for this State, or for any of its political subdivisions, such as a county, city, town, township, or borough to engage in the construction of any public work involving engineering, unless the plans and specifications and estimates have been prepared by, and the construction executed under the direct supervision of, a registered professional engineer; provided, that nothing in this Section shall be held to apply to any public work wherein the expenditure for the complete project of which the work is a part does not exceed two thousand dollars ($2,000.00).

## INTERSTATE REGISTRATION

*Section 19.* The Board may, upon application therefor, and the payment of a fee of ten dollars ($10.00), issue a Certificate of Registration as a Professional Engineer to any person who holds a Certificate of Qualification of Registration issued to him by proper authority of the National Council of State Boards of Engineering Examiners, or of the National Bureau of Engineering Registration, or of any State or Territory or Possesion of the United States, or of any Country, provided that the applicant's qualifications meet the requirements of this Act and the rules established by the Board.

## REVOCATIONS

*Section 20.* The Board shall have the power to revoke the certificate of registration of any registrant who is found guilty of:

(a) The practice of any fraud or deceit in obtaining a certificate of registration;

(b) Any gross negligence, incompetency, or misconduct in the practice of engineering or land surveying as a registered professional engineer or land surveyor.

Any person may prefer charges of fraud, deceit, gross negligence, incompetency, or misconduct against any registrant. Such charges shall be in writing, and shall be sworn to by the person making them and shall be filed with the Secretary of the Board.

All charges, unless dismissed by the Board as unfounded or trivial, shall be heard by the Board within three months after the date on which they shall have been preferred.

The time and place for said hearing shall be fixed by the Board, and a copy of the charges, together with a notice of the time and place of hearing, shall be personally served on or mailed to the last known address of such registrant, at least thirty days before the date fixed for the hearing. At any hearing, the accused registrant shall have the right to appear personally and by counsel, to cross-examine witnesses appearing against him, and to produce evidence and witnesses in his own defense.

If, after such hearing, three or more members of the Board vote in favor of finding the accused guilty, the Board shall revoke the certificate of registration of such registered professional engineer or land surveyor.

## REISSUANCE OF CERTIFICATES

The Board, for reasons it may deem sufficient, may reissue a certificate of registration to any person whose certificate has been revoked, providing three or more members of the Board vote in favor of such reissuance. A new certificate of registration, to replace any certificate revoked, lost, destroyed, or mutilated, may be issued, subject to the rules of the Board, and a charge of three dollars ($3.00) shall be made for such issuance.

## APPEALS

Any person who shall feel aggrieved by any action of the Board in denying or revoking his certificate of registration may appeal therefrom to the .....[*] and, after full hearing, said Court shall make such decree sustaining or reversing the action of the Board as to it may seem just and proper.

## VIOLATIONS AND PENALTIES

*Section 21.* Any person who shall practice, or offer to practice, engineering or land surveying in this State without being registered in accordance with the provisions of this Act, or any person presenting or attempting to use as his own the certificate of registration or the seal of another, or any person who shall give any false or forged evidence of any kind to the Board or to any member thereof in obtaining a certificate of registration, or any person who shall falsely impersonate any other registrant of like or different name, or any person who shall attempt to use an expired or revoked certificate of registration, or any person who shall violate any of the provisions of this Act, shall be guilty of a misdemeanor, and shall, upon conviction, be sentenced to pay a fine of not less than one hundred dollars ($100.00), nor more than five hundred dollars ($500.00), or suffer imprisonment for a period not exceeding three months, or both.

It shall be the duty of all duly constituted officers of the law of this State, or any political subdivision thereof, to enforce the provisions of this Act and to prosecute any persons violating same. The Attorney General of the State or his assistant shall act as legal adviser of the Board and render such legal assistance as may be necessary in carrying out the provisions of this Act.

## SAVING CLAUSE

*Section 22.* This Act shall not be construed to prevent or to affect:

(a) **The practice of any other** legally recognized profession or trade; or

(b) **The practice of a person not a resident of** and having no established place of business in this State, practicing or offering to practice herein the profession of engineering or land surveying, when such practice does not exceed in the aggregate more than thirty days in any calendar year; provided, such person is legally qualified by registration to practice the said profession in his own State or Country in which the requirements and qualifications for obtaining a certificate of registration are not lower than those specified in this Act; or

(c) **The practice of a person not a resident** of and having no established place of business in this State, or **who has recently become a resident** thereof, practicing or offering to practice herein for more than thirty days in any calendar year the profession of engineering or land surveying, if he shall have filed with the Board an application for a certificate of registration and shall have paid the fee required by this Act; provided, that such a person is legally qualified by registration to practice said profession in his own State or Country in which the requirements and qualifications for obtaining a certificate of registration are not lower than those specified in this Act. Such practice shall continue only for such time as the Board requires for the consideration of the application for registration; or

(d) **The work of an employee or a subordinate** of a person holding a certificate of registration under this Act, or an employee of a person practicing lawfully under Paragraphs (b) or (c) of this Section; provided such work does not include final designs or decisions and is done under the direct responsibility, checking, and supervision of a person holding a certificate of registration under this Act or a person practicing lawfully under Paragraphs (b) or (c) of this Section; or

(e) **The practice of officers and employees of the Government** of the United States while engaged within this State in the practice of the profession of engineering or land surveying, for said Government.

## INVALID SECTIONS

*Section 23.* If any Section or Sections of this Act shall be declared unconstitutional or invalid, this shall not invalidate any other Sections of this Act.

## REPEAL OF CONFLICTING LEGISLATION

*Section 24.* All laws or parts of laws in conflict with the provisions of this Act shall be, and the same are hereby, repealed.

[18] It is suggested that the Board regulate the exact method of fulfilling the requirement that plans, specifications, plats, and reports shall be stamped. For example, the Board may rule that every sheet be stamped; or that the title or first sheet only need be stamped; or that only contract documents, or documents of record be stamped; etc.

[18] In States where registrants are few, the annual renewal fee may be $5, but in larger States $1 may be sufficient.

[*] Insert name of proper Court.

# Planning Committee Releases Progress Reports

As of March 27, 1946, the following interim reports were received by the AIEE committee on planning and co-ordination and released by Chairman James F. Fairman for publication. These reports were presented by Mr. Fairman to the April 10 meeting of the executive committee of the board of directors at headquarters in New York, N. Y.

## SUBCOMMITTEE ON PROFESSIONAL ACTIVITIES

The following report was prepared by T. G. LeClair (F '40) chairman of the professional activities subcommittee.

*Change Status of Special Committee on Registration of Engineers.* A recommendation to replace the present special committee by a standing committee was approved by the committee on planning and co-ordination and by the executive committee on December 11, 1945. The subcommittee, at the request of the board of directors, prepared a draft of the "scope and duties" of the proposed standing committee for incorporation in the bylaws. This draft was approved by the committee on planning and co-ordination and submitted to the board. (Editor's Note: Proposed bylaw revision reviewed by executive committee at April

10, 1946, meeting and approved in principle and referred to committee on constitution and bylaws.)

*Recommendation to Approve and Aid Formation of Joint Student Branches.* This recommendation likewise was approved by the committee on planning and co-ordination and by the executive committee. The President requested the committee on Student Branches to work with representatives of other societies in developing a specific plan of co-operation. A subcommittee is actively at work on this project. (Editor's Note: Approved by the board of directors at its winter convention meeting January 24, 1946, on the basis of the recommendation made by the committee on planning and co-ordination, which included the clarifying statement that "it should be emphasized that the intention of this suggested change in policy is to make joint Student Branches permissive wherever such an organization would be beneficial, and not to make the joint branch mandatory.")

*Establish a New Institute Office to Relieve the Burden of the Presidency.* From a number of proposals, the subcommittee recommended to the committee on planning and co-ordination the establishment of an elective office of senior vice-president. Although there is general agreement that something should be done to assist the president, and to secure the guidance of a wider acquaintance with the membership and workings of the Sections in the appointment of committees, the committee on planning and co-ordination sent the recommendation back to the subcommittee for further study. After reconsideration the subcommittee decided to continue its efforts to establish an elective office of the executive vice-president type.

*Organization of the Engineering Profession.* The subcommittee drew up four possible plans of organization and, after experience gained at the winter convention conference on January 23, 1946, has revised its plans for publication in the April issue of *Electrical Engineering*. In addition to publication these plans are to be discussed at three District meetings in April and May and at several Section meetings also. These discussions will cover the work of both subcommittees, and questionnaires have been developed for use in obtaining views of those who attend discussion meetings and of other active members. The results of these questionnaires will be brought to the attention of the committee on planning and co-ordination after enough returns have been received to be significant. (Editor's Note: Representatives of the committee on planning and co-ordination have been invited to attend various District and Section meetings to discuss the work of the committee and to gain direct membership reactions for the guidance of the committee in its further work. W. S. Hill (M '30) of Buffalo, represented the professional activities subcommittee at a meeting of the Boston Section February 15, and at a conference held during the North Eastern District meeting at Buffalo, April 24–26. J. F. Fairman of New York (F '35) chairman of the committee on planning and co-ordination, attended a meeting of the Pittsfield Section, February 19, the annual meeting of the New York Section, April 25, the annual meeting of the Lynn Section, April 30, and is scheduled to attend the Southern District meeting at Asheville, N. C., May 14–16. T. G. LeClair of Chicago, chairman of the professional activities subcommittee, led the conference discussion at the South West District meeting in San Antonio, April 16–18.)

*Activities of Special Interest to Young Employed Engineers.* The subcommittee is endeavoring to find out what the problems and needs of the younger engineer-employees are, and what can be done by the Institute to get and keep their interest.

*Other Recommendations.* The subcommittee has on its agenda other items for which definite recommendations will be prepared and submitted to the committee on planning and co-ordination at a later date.

### SUBCOMMITTEE ON TECHNICAL ACTIVITIES

The following report was prepared by M. D. Hooven (F '44) chairman of the technical activities subcommittee, and also chairman of the AIEE technical program committee.

*Review of Functioning of Technical Organization of Other Societies.* The method of operation of some 30 national engineering societies was reviewed in detail by the various technical committee chairmen. Their comments and reports were analyzed and presented at the March 15 meeting of the technical program committee, this material being considered as background for further discussion of the organization of the technical activities of AIEE. Having served their purpose the reviews will be turned over informally to the Engineers' Joint Council.

*Additional Convention to Be Held in Chicago.* The subcommittee, acting at the behest of the technical program committee, has reported to the planning and co-ordination committee that for the purpose of providing an outlet for more technical papers and for initiating the technical activities of the Institute earlier in the administrative year, Section 27 of the bylaws be changed to add an October convention, to the three national conventions now held. (Editor's Note: Approved by executive committee of the board of directors at meeting April 10, 1946; proposed amendment to bylaws to be referred to committee on constitution and bylaws.)

*Winter (New York) Convention to Be Held in Hotel.* The subcommittee, with the support of the technical program committee, has recommended to the expiring winter convention committee that it transmit to its successors an instruction that effort should be made to hold the next winter's convention in a hotel rather than in the Engineering Societies Building. The winter convention committee is making this recommendation to the board of directors. (Editor's Note: Approved in principle by the executive committee of the board of directors at meeting April 10, 1946, subject to final action by the board.)

*Exhibits in Conjunction With Convention or District Meetings.* The subcommittee, pursuant to a motion of the technical program committee that the Institute actively take under advisement the matter of sponsoring exhibits in conjunction with conventions, has recommended to the winter convention committee that Section 29 of the bylaws be revised to include rather than exclude the possibility of exhibits of commercial products. The winter convention committee is recommending this change to the board of directors. (Editor's Note: Approved in principle by the executive committee of the board of directors at meeting April 10, 1946, subject to final action by the board.)

*District Meetings on Specific Subjects.* At the 1946 winter convention conference, Professor Turner spoke on the advisability of holding technical conferences on specific subjects at specific locations, an idea that has received support from many sources. The subcommittee has recommended to the technical program committee that beginning immediately effort should be made to present national programs on specific subjects at District meetings located at points where some particular theme might be of importance. The technical program committee in endorsing the idea has recommended to the technical committees that such sessions be planned as soon as possible. The secretary of the technical program committee has been instructed to co-ordinate this activity with each District planning to sponsor a meeting during the next administrative year.

*Closer Co-operation With Committees of Other Organizations.* In discussion of Plan A (The Coover proposal for a combined electrical engineering society) at the technical program committee meeting of March 15, it was agreed generally that open overtures for union should not as yet be made to other national electrical engineering bodies, but that closer co-operation with them on technical work should be immediately entered into. Accordingly, a motion was passed that the secretary write to the chairmen of all technical committees calling attention to Section 86 of the bylaws which encourages such co-operation, urging each chairman to review all contacts and explore the possibility of establishing others. Since that meeting, several possibilities of joint meetings with outside technical committees have come up for consideration.

*Problems of Papers Arising in Joint Meetings With Other Societies.* In the discussion of greater co-operative technical effort with other societies as outlined in the foregoing item, the traditional prohibition of joint publication of papers with other societies was discussed with the result that the technical program committee voted to urge that consideration be given to joint publication of papers of mutual interests with other engineering bodies. Since the ban seems

to be in the sentence, "No manuscript, any appreciable portion of which has been published elsewhere, is acceptable," which is contained in the publication committee portion of the pamphlet, "Information for Authors," the subcommittee has entered into discussion with the publication committee concerning the lifting of this limitation.

*General Publication Policy.* It developed in the discussion of the previous item that there were many views as to how the general publication policy of the Institute could be bettered. In its past work of accumulating suggestions on the technical organization of the Institute, the subcommittee has received scores of such suggestions. It is at present compiling and correlating these suggestions into compact form for discussion with the publication committee and for further discussion at the next meeting of the technical program committee.

*Organization of Institute Technical Activities.* Subsequent to the 1946 winter convention conference discussion on the Alger proposal, the receipt of similar proposals, and technical program committee discussion of possible variations in the original one, the technical program committee voted that at its May meeting the chairmen of the technical committees present should be prepared to form councils where there are mutual interests. These councils will meet in the afternoon and discuss further methods of co-ordinating the activities of technical committees which lie in the same field.

# Standard on Automatic Stations Revised to Include New Material

Standard definitions, standard tests, and a standard language of numbers for identifying on drawings and on the devices themselves the many complicated devices making up a complete equipment are given in the revised "American Standard for Automatic Station Control, Supervisory, and Telemetering Equipment," C37.2-1945. The new standard also includes a table indicating the minimum protection that should be given to power apparatus and feeders.

With this new national Standard, which provides dielectric tests for supervisory control and telemetering equipment, it is expected that the use of such remote-control equipment will be increased and that easier operation of all centralized systems of electric power control will result.

Originally prepared as AIEE Standard 26, by the Institute's committee on automatic stations, the Standard was referred to committee C37 in 1936, and reissued as an approved American Standard in October of 1937. Early in 1945 the 1937 edition was revised and enlarged by the AIEE committee on automatic stations, later reviewed by the ASA Sectional Committee on Power Switchgear C37, and approved as an American Standard December 11, 1945. More accurately to fit the enlarged scope, the title was changed in the revision to the "American Standard for Automatic Station Control, Supervisory, and Telemetering Equipment." Minor changes also were made in the definition, to correspond to the definitions for these same terms in related American Standards, such as those for a-c power circuit breakers.

The following digest of the revised standard is based upon material prepared by George Sutherland (F '27) of the Consolidated Edison Company of New York, Inc., and G. S. Lunge (A '23) of the General Electric Company, Schenectady, N. Y. Mr. Sutherland is chairman of the ASA Sectional Committee on Power Switchgear C37, and represents the Electric Light and Power Group. Mr. Lunge is secretary of the same committee and represents the AIEE.

## NEW MATERIAL NOW INCLUDED

Because the close similarity of many names of feeder types (stub feeder; multiple feeder; stub-multiple feeder; and so forth) may lead to confusion, simple one-line diagrams now are used to illustrate the definitions for these terms.

Another important addition in the new Standard is the specification of dielectric test voltages for supervisory control and telemetering equipments. Such equipment is not covered by any other existing American Standard, whereas practically all other individual devices used in automatic stations already are governed by existing national standards.

## PRINCIPAL CHANGES SINCE 1937

One of the principal changes in the Standard since the 1937 edition concerns the use of numbers for device functions. Each device in an automatic switching equipment has a device function number which is placed adjacent to the device symbol on all wiring diagrams and arrangement drawings. In addition it is attached to or located adjacent to each device, so that it may be readily identified.

When device function numbers were first introduced for use in automatic stations, each manufacturer established his own standard series of numbers from 1 to 99. Later, to the temporary discomfiture but ultimate satisfaction of those having to use elementary or other diagrams for automatic station equipment, a single series of device function numbers from 1 to 99 for use by all manufacturers was adopted.

It was this common language of automatic switchgear practice that appeared in the "AIEE Standard 26 for Automatic Stations" published in April 1928 and revised in 1930. A few changes in the meanings of these standard numbers were made in the 1937 edition of the "American Standard for Automatic Stations," chiefly in the direction of generalizing or broadening the significance of some of these numbers. This tendency is again evident in the 1945 edition of the Standard.

## NEW FUNCTIONS DEVELOPED RECENTLY

During the last eight years, the need for certain device functions has largely disappeared, at least in new equipments, and the standard device numbers thus freed have been eagerly seized upon to cover new functions that were not contemplated a quarter of a century ago when use of these standard device numbers first became general. Increasing use of mercury-arc rectifiers, distance relays, and pilot protection schemes, for example, has occasioned the use of some new device function numbers. More recently it has become common practice to use these convenient numbers for *all* types of switchgear equipments and not in automatic stations only.

This also has made it desirable to include 29 standard letter suffixes for the device numbers (instead of the 17 suffixes in the 1937 Standard), and further expansion of these undoubtedly will occur in the future. The letter *A*, for example, is used to indicate air, automatic, or accelerating auxiliary devices; *B* for blower; and *BB* for bucking bar for high speed circuit breaker.

Only 99 different standard device numbers are conveniently possible. When, for instance, the meaning of automatic device 4 in a machine equipment is established, this also fixes the meaning of devices 104, 204, and 304 in a reclosing (or automatic transfer) feeder, supervisory controlled machine, and supervisory controlled feeder equipment, respectively. Of these 99 in the 1937 Standard, 13 were unassigned and could be used at will. In the 1945 edition of the Standard only 8 are still available for such miscellaneous functions in individual installations.

Gone from the list are:

57. Current regulating relay (now 90C)
58. Voltage regulating relay (now 90V)
84. Generator relay (now combined with exciter relay 53)
85. Commutation control relay
95. Closing relay

Newly assigned device function numbers include:

7. Anode circuit breaker
21. Impedance relay
69. Permissive control device
74. Alarm relay
75. Position changing mechanism (for a removable circuit breaker unit)
77. Impulse transmitter
81. Frequency device
85. Carrier (or pilot wire) receiver relay

These 99 standard device numbers constitute the switchgear equipment engineer's shorthand, which already has saved an incalculable amount of time in making and using electrical diagrams and instruction books. By using numbers rather than letters for the basic functional designations,

this system transcends language barriers and may in time become international. It is also conveniently usable with appropriate letter suffixes to designate auxiliary devices or important electrical components of a complicated device.

A few changes also will be noticed in the table showing the minimum protection to be provided for automatically controlled power apparatus and feeders. In addition to naming the types of protection required, this table now lists the function numbers of the devices, one or more of which would be used to provide each type of protection.

An automatic station, if unattended, ordinarily will contain, besides the main power apparatus (machines, transformers, rectifiers, and so forth):

(*a*). Automatic switching equipment, *to control the individual steps* involved in putting each machine or feeder in or out of service. This uses devices in the series 1 to 99 and 101 to 199.

(*b*). Telemetering equipment, to give the dispatcher or supervisor, located elsewhere, *quantitative information* on the performance of the machines or circuits in the automatic station.

(*c*). Supervisory control and indication equipment, *to show the dispatcher, by means of lamps* and audible signals, the operating position of all circuit breakers and power-operated switches and *permit him to control* the station remotely. This uses devices in the series 201 to 299 and 301 to 399.

The 1937 edition of the Standard covered only the first of these three classes of equipment. Although some small automatic stations have no provision for remote (supervisory) control of machine output or voltage level, and the machines start and stop automatically in response to water-level, voltage, or current conditions, or to a time switch, in the majority of recent installations supervisory control of these functions is considered an indispensable adjunct to the automatic switching equipment at the unattended station. The fact that an American Standard is available governing at least the dielectric test requirements for supervisory control and telemetering equipment should increase confidence in such equipment and foster its wider application, with resulting increased ease of centralized system operation.

# Standards Proposed for Pool-Cathode Mercury-Arc Power Converters

Representing the first such venture into the field of mercury-arc rectifiers, a "Proposed Standards for Pool-Cathode Mercury-Arc Power Converters" has been prepared under the auspices of the subcommittee on electronic power converters of the AIEE committee on electronics. This new draft is an up-to-date revision of the original AIEE "Report (number 6) on Standards for Acceptance Tests for Metal Tank Mercury-Arc Rectifiers" issued in June 1934. Currently, this material is being processed at AIEE headquarters in New York, and is expected very soon to be available in the form of a "Report on Proposed Standards" which will be available from the secretary of the AIEE Standards committee at Institute headquarters, 33 West 39th Street, New York 18, N. Y.

These proposed standards have not been approved by the AIEE Standards committee, nor have they been considered by the American Standards Association's C34 Sectional Committee. Publication previous to approval by these groups is made to present the proposed Standards to a wider engineering public and to facilitate suggestions and criticism.

The need for adequate standards has been recognized for some time. The only material of standards form previously available has been the AIEE "Report on Standards for Acceptance Tests for Metal Tank Mercury-Arc Rectifiers" number 6 issued in June 1934. This report is only tentative in nature and does not cover many recent developments such as the ignitron, excitron, sealed tubes, and the use of phase control. The large number, size, and variety of applications made since the issuance of Report 6 has provided an excellent background for the development of the new Standards.

The new terms and definitions proposed in the Standards are a feature of particular interest. They represent an endeavor to provide a systematic nomenclature and an exact terminology embodying the basic concepts of rectifiers. The development of an exact terminology has required the selection and definition of new terms and the redefinition of old terms. These terms have been defined to conform primarily with practice in the power rectifier field, although cognizance has been taken of established practice in other fields employing rectifiers. It is proposed that the terminology developed in these Standards be adopted for all rectifiers where applicable. This would eliminate some of the present confusion caused by the lack of an exact terminology.

As a preview, some of the salient features of the proposed Standards are presented in the following paragraphs, as prepared by Professor C. H. Willis (F '42) of Princeton University, who is chairman of the subcommittee on electronic power converters of the AIEE committee on electronics, and also chairman of the ASA Sectional Committee C-34 on Mercury-Arc Rectifiers. Many of the factors entering into the development of the terms and the definitions of the new terminology also are discussed.

## SCOPE

These standards apply to all types of mercury-arc power converters, employing rectifying devices with mercury pool cathodes and used for power conversion purposes, including mercury-arc power rectifiers, mercury-arc power inverters, electronic frequency changers, and converters used with electronic motors when these equipments employ mercury-arc rectifying devices with pool cathodes. These standards do not apply to welding rectifiers nor electronic power converters employing rectifying devices with thermionic cathodes.

## DEFINITIONS

The development of the new Standards has necessitated the definition of a large number of terms, some of which have become established by usage, and others are new terms which have been devised to meet growing needs. There also has been need for the development of a consistent and systematic nomenclature, adequate for immediate needs yet flexible enough to provide for future development.

In the preparation of definitions the "American Standard Definitions of Electrical Terms," ASA C42, 1941, has been used as a guide. Wherever possible the terms and definitions set forth in this Standard have been adopted. However, new terms or new definitions have been proposed wherever the existing definitions were inadequate or inconsistent.

The terminology of the new Standards provides a systematic nomenclature for device names, circuit names, and the classification of circuits. The essential features of this nomenclature are as follows.

*Device Names.* The system of device names starts with the elemental device, builds up the various apparatus assemblies, and concludes with the complete equipment. The first of the device names are structurally descriptive. They start with the general term "electron tube" and proceed with the more restrictive terms, "gas tube" and "pool tube."

*1.001 Electron Tube.* An electron tube is a device consisting of an evacuated enclosure containing a number of electrodes between two or more of which conduction of electricity through the vacuum or contained gas may take place. (70.10.010 Mod)

*1.002 Gas Tube.* A gas tube is an electron tube in which the pressure of the contained gas or vapor is such as to affect substantially the electrical characteristics of the tube. (70.10.020 Mod)

*1.008 Pool Tube.* A pool tube is a gas tube with a pool cathode.

The second group of device names are functionally descriptive. These are the "rectifying device" and various components.

*1.009 Rectifying Device.* A rectifying device is an elementary device, consisting of one anode and its cathode which has the characteristic of conducting current effectively in only one direction.

*1.003 Anode (of an electron tube).* An anode of an electron tube is an electrode to which a principal electron stream flows. (70.15.005 Mod)

*1.004 Cathode (of an electron tube).* A cathode of an electron tube is an electrode which is the primary source of electron emission. (70.15.015 Mod)

The term "rectifier" has a wide usage as a general name. It was felt that this usage had become so well established that it would be undesirable and impractical to change it, and therefore it has been retained and defined in accordance with present practice.

*1.010 Rectifier.* A rectifier is an integral assembly of one or more rectifying devices.

*1.011 Mercury-Arc Rectifier.* A mercury-arc rectifier is a rectifier consisting of one or more mercury-vapor gas tubes.

Various types of rectifiers are defined as follows: Single-anode tube (tank), multi-anode tube (tank), ignitron, excitron, pumped rectifier, and sealed tube.

Complete equipments employing rectifying devices may function in several ways, namely as rectifiers, inverters, frequency changers, and so forth, and a need was felt for a general term covering all such equipments. It is proposed to cover such equipments under the general term "electronic power converter."

*1.018 Electronic Power Converter.* An electronic power converter is an equipment which employs electronic devices for transforming electric power.

The term "rectifier unit" is used to describe a complete operative assembly as follows:

*1.019 Rectifier Unit.* A rectifier unit is an operative assembly consisting of the rectifier(s), the rectifier auxiliaries, the rectifier transformer equipment, and the essential switchgear. (15.50.040 Mod)

Various types of operation are defined by the terms "power rectifier," "power inverter," "electronic frequency changer," and so forth.

*Classification of Circuits.* A confusing and unsatisfactory circuit nomenclature has grown up as a result of the application of the terms "half wave" and "full wave" to polyphase power rectifier circuits. In order to avoid these difficulties, the terms "single way" and "double way" have been proposed.

*1.202 Single-Way Rectifier.* A single-way rectifier is a rectifier in which the current between each terminal of the alternating voltage circuit and the rectifying element (or elements) conductively connected to it flows only in one direction.

*1.203 Double-Way Rectifier.* A double-way rectifier is a rectifier in which the current between each terminal of the alternating voltage circuit and the rectifying elements conductively connected to it flows in both directions.

The terms single-way and double-way provide a means for describing the effect of the rectifier circuit on current flow in transformer windings connected to rectifiers. Most rectifier circuits may be classified in these two general types. In practice a circuit is assumed to be single-way unless it is specifically stated as double-way.

It is recognized that the terms "half wave" and "full wave" have a wide usage and are entrenched so firmly in practice that it would be impractical to supplant them. Definitions of these terms are not included in the proposed standards but in order to prevent the erroneous use of these terms and yet retain them, it is suggested that they be redefined as follows:

*Half-Wave Rectifier Circuit.* A half-wave rectifier circuit is a circuit which has a single rectifying element and changes alternating current into unidirectional current, utilising only one half-cycle of the a-c wave. (Refer to ASA 60.41.010 and 65.20.030.)

*Full-Wave Rectifier Circuit.* A full-wave rectifier circuit is a circuit which has two rectifying elements and changes alternating current into unidirectional current, utilising both half-cycles of the a-c wave. (Refer to ASA 60.41.015 and 65.20.025.)

To facilitate classification of the different circuits on the basis of circuit action, the "commutating group" is defined.

*1.305 Commutating Group.* A commutating group of a rectifier is a group of rectifying elements and the alternating voltage supply elements conductively connected to them in which the direct current of the group is commutated between individual elements which conduct in succession.

Simple, multiple, parallel, cascade, and series rectifiers are defined in terms of the arrangement and number of the commutating groups.

In the analysis of rectifier circuits, one or more rectifying devices may be treated as a single circuit element. Such a circuit element is defined as a "rectifying element."

*1.201 Rectifying Element (circuit element).* A rectifying element is a circuit element which has the property of conducting current effectively in only one direction.

When a group of rectifying devices is connected, in either parallel or series arrangement, to operate as one circuit element, the group of rectifying devices should be considered as a rectifying element.

The windings of rectifier transformers are identified by the terms "d-c winding" and "a-c winding." These terms avoid the difficulties encountered in the use of the terms primary, secondary, high voltage, and low voltage when applied to transformers for electronic power converters.

*5.102 D-C Winding of Rectifier Transformer.* The d-c winding of a rectifier transformer is the winding which is connected conductively to the main electrodes of the rectifier, or which conducts the direct current of the rectifier.

*5.103 A-C Winding of Rectifier Transformer.* The a-c winding of a rectifier transformer is the winding which is connected to the a-c circuit and usually has no conductive connection with the main electrodes of the rectifier.

*Circuit Names.* A comprehensive table of rectifier circuits giving circuit diagrams and names is included in the Standards. This rectifier circuit nomenclature is based on a descriptive name given in the following order:

1. The connection of the transformer a-c windings.
2. The number of phases of the rectifier unit.
3. The connection of the transformer d-c windings and rectifying elements.
4. Type of circuit (that is, single-way or double-way, single-way assumed unless otherwise stated).

In describing multiple rectifiers the prefixes double, triple and quadruple are used to indicate the number of component simple rectifiers and the names diametric, wye, cross, star, zig-zag, fork, aster, and so forth, are used to denote the connection of each component simple rectifier. The circuits are shown in Table II of the Standard.

### STANDARDS

Standards establish usual and unusual service conditions, designate classifications for ratings, prescribe the basis on which performance characteristics shall be specified, and specify certain minimum requirements for acceptance tests.

The standards include a treatment of rectifier performance characteristics with phase control.

### TEST CODE

The test code sets forth accepted test practices as a guide in making acceptance tests to demonstrate the performance of rectifier units. It applies to both the rectifier units and their component parts.

Features of this test code are a new method for measuring arc drop with the rectifier operating under load and procedure for determining power factor and regulation.

### RECOMMENDED PRACTICE AND OPERATING GUIDE

This guide covers general recommendations for loading and operating rectifier units of the type covered by the standards.

In connection with this part of the proposed standards, a report titled "Inductive Co-ordination Aspects of Rectifier Installations" has been prepared covering the procedure for predicting the effect of rectifier wave shape upon adjoining communication systems.

### RECTIFIER TRANSFORMERS

Inasmuch as the action of the rectifier imposes definite and special requirements on the associated transformer equipment, a supplementary section on transformers is included in the standards. It is expected that this eventually will be incorporated in the appropriate transformer standards.

It is proposed that standard name-plate markings for rectifier transformers shall include the commutating reactance of a single commutating group expressed in line-to-neutral ohms referred to the d-c winding, in addition to the usual percentage impedance which usually is given on power transformers. The proposed transformer standards also include two methods for determining rectifier transformer load losses for the various circuits given in the table of circuits.

Copies of the proposed standards may be obtained upon request from: the Secretary, AIEE Standards Committee, 33 W. 39th Street, New York 18, N. Y., and comments pertaining to them should be sent to the same address.

## Members Urged to Place "Supplement" Orders Early

Members desiring the June 1946 *Supplement to Electrical Engineering—Transactions Section* are urged to place their orders before June 15, 1946, to insure obtaining their copies upon publication. Members with standing orders, however, need make no further reservation; upon notification to Institute headquarters, a standing order may be arranged at any time.

This supplement to *Electrical Engineering* will contain technical paper discussions which are not published in the monthly issues. Its price is 50 cents to members and it may be ordered from the AIEE Order Department, 33 West 39th Street, New York 18, N. Y. Further details of the supplement's contents and availability will be announced in this section in a subsequent issue.

* Paragraph numbers of terms defined in ASA C42-1941 are given in parentheses, and, if a change in the C42 definition is proposed, the notation "Mod" is added. Unmarked definitions are new.

## San Francisco Section Fetes Past Officers

The AIEE San Francisco Section feted past officers of the Section at a gala dinner meeting on April 1, 1946, "Institute Officers' Night." The past officers were honored during the first portion of a twin program. Of 30 living past chairmen and officers, two, AIEE secretary H. H. Henline (F '43) New York, N. Y., and P. B. Garrett (M '30) editor, *Electric Light and Power*, Chicago, Ill., responded by mail and 24 were present in person for the occasion. Section Chairman D. I. Ansini (M '38) turned over the introduction of the past chairmen to S. J. Lisberger (F '39) chairman of the San Francisco Section during 1910–11, the oldest chairman present in point of time of chairmanship.

The second portion of the program was devoted to an address by AIEE President William E. Wickenden (F '39) on "Engineers and Public Policy." Doctor Wickenden's address before the San Francisco Section was one of three Institute appearances in the San Francisco Bay region during his recent tour of Districts 8 and 9 (Pacific and North West Districts). He also had spoken to the University of California Branch on "Science and Security" as well as visiting at the Stanford University Branch. Mrs. Wickenden was among the women present.

The following past officers attended the meeting:

*Past Chairmen* S. J. Lisberger, 1910–11; J. P. Jollyman, 1920–21; W. P. L'Hommedieu, 1921–22; J. A. Koontz, 1923–24; F. R. George, 1924–25; D. I. Cone, 1926–27; W. L. Winter, 1927–28; B. D. Dexter, 1928–29; L. F. Fuller, 1929–30; E. A. Grellin, 1931–32; E. F. Maryatt, 1932–33; W. C. Smith, 1933–34; A. M. Bohnert, 1934–35; E. M. Wright, 1935–36; H. S. Lane, 1936–37; R. O. Broemer, 1937–38; F. S. Benson, 1938–39; C. A. Andrews, 1939–40; M. S. Barnes, 1941–42; B. L. Robertson, 1942–43; C. E. Baugh, 1943–44; and G. C. Tenney, 1944–45. Also *Past Secretary* A. G. Jones, 1910–29; and A. W. Copley, former *vice-president* of District 8, 1931–33.

Regrets were received from the following:

*Past Chairmen* C. W. Burkett, 1908–09; H. H. Henline, 1922–23; R. C. Powell, 1925–26; P. B. Garrett, 1930–31; and C. V. Fowler, 1940–42.

## Washington Section Concludes Year With Technical Groups

April 1946 marked the conclusion of the AIEE Washington Section's first year of experience with technical discussion groups. The program for the year provided for eight scheduled meetings under the auspices of five groups which were organized under the direction of W. J. Lynott, Jr., (M '42). Under this system the following groups were formed and a chairman appointed for each to obtain speakers and to preside over the meetings: electronics, Albert Preisman (M '41), chairman; communications, Davis S. Bender (M '42), chairman; research, Almon W. Spinks (M '45), chairman; power, William J. Lank (M '42), chairman; and electrical engineering mathematics, H. L. Sangster (A '41), chairman.

The selection and number of subjects for discussion during the sessions of the technical groups was influenced by the replies to a questionnaire sent to the membership. This questionnaire indicated that 125 members preferred electronics, 83 preferred communications, 61 preferred electrical research, 60 preferred power systems, and 48 preferred electrical engineering mathematics. On the basis of this information the following subjects were presented: "The Cyclotron, Its Theory and Application," by Dean B. Cowie, Carnegie Institute of Washington; "Frequency Modulated Broadcasting," Everett L. Dillard, owner of radio station WBXL; "Power System Planning," W. F. Lank and F. S. Black (M '44), Potomac Electric Power Company; "Self-Synchronous Transmission Units," M. R. Walters, Bureau of Ordnance, Navy Department; "Important Concepts of Electrical Engineering Mathematics," E. L. Harder (M '41), Westinghouse Electric Corporation; "The Electron Microscope," James Hillier, RCA Laboratories; "Multistation Microwave Chain Radio Transmission," H. S. Black (F '41), Bell Laboratories; and "A Survey of Microwave Radio Measurements," Harold Lyons, Radio Section, National Bureau of Standards.

**Seated left to right at the San Francisco Section dinner are: W. C. Smith (F'40), President Wickenden, Section Chairman Ansini, and Past Chairmen Lisberger and Jones**

## Niagara Subsection Holds Inaugural Meeting

The newly formed AIEE Niagara District Subsection held an inaugural meeting and dinner at the Foxhead Inn, Niagara Falls, Ontario, Canada, on March 21, 1946, with 50 members and guests in attendance. This Subsection developed out of the AIEE Niagara District discussion group and will continue to co-operate with the Niagara Falls (N. Y.) Subsection in all activities.

A. H. Frampton (F '45) chairman of the Toronto (Ontario) Section was in charge of the preliminary proceedings and conducted the election of the executive officers of the Subsection. The following officers were elected: *chairman*, J. I. Gram (M '28); *secretary-treasurer*, W. G. A. Barr (A '44); *chairman of program committee*, C. W. Baker (M '34); and *chairman of membership committee*, E. O. Scott (A '36). Congratulations were tendered the Niagara District members on the formation of the Subsection by J. T. Thwaites (M '44) representing the Hamilton (Ontario) Subsection and E. Bond (M '43) representing the Niagara Falls Subsection.

The second portion of the program, under the chairmanship of Mr. Gram, was devoted to an address by G. D. Floyd (M' 28) Hydro-Electric Power Commission of Ontario, on "Field Tests of the Interrupting Capacities of 138-Kv Oil Circuit Breakers." The address was followed by a discussion period. K. V. Farmer (M '21) proposed a vote of thanks to the speaker.

## Pittsfield Section Studies Organization of Profession

To give fullest consideration to proposals to reorganize the engineering professional societies, the AIEE Pittsfield Section recently devoted two meetings with featured addresses and informal discussion to that subject. The meetings will be supplemented by news letters, and distribution of a questionnaire is comtemplated to bring as much information as possible before the Section membership.

At the first meeting held February 19, James F. Fairman (F '35) AIEE vice-president and chairman of the committee on planning and co-ordination, spoke on "Organization of the Engineering Profession." For several weeks before the meet-

ing, interested individuals and committee members had participated in numerous discussions concerning the subject, and a round table conference with Mr. Fairman was held during the afternoon preceding the meeting.

In his address Mr. Fairman reviewed the work of his two special committees on technical and professional activities and the four tentative plans of reorganization of the engineering profession.

AIEE President W. E. Wickenden addressed the section on the same topic on March 15.

**New Discussion Group Meets.** The first meeting of the newly formed basic science discussion group of the Philadelphia Section was held jointly with the Franklin Institute on March 27, 1946, with approximately 218 members and guests in attendance. C. N. Weygandt (A '37) of the University of Pennsylvania addressed the group on the theory of servomechanisms. The talk, which was illustrated by slides and demonstrations of models of servomechanisms, was followed by a lengthy discussion period.

**Delaware Student Branch.** Resumption of activities by the University of Delaware Student Branch on March 26, 1946, was announced by Miss Frances B. Cummins, Student Member, at a recent meeting of the Wilmington Subsection. During the past two years the Wilmington Subsection has been filling the gap in activities of the Student Branch by inviting the Student Members and members of the faculty to attend the Subsection's meetings. The University of Delaware Student Branch's first meeting was based on electrical heating with a talk by Miss Cummins on "Dielectric Heating" and a motion picture on induction heating as features.

# ABSTRACTS • • •

**TECHNICAL PAPERS previewed in this section will be presented at the AIEE Southern District meeting, Asheville, N. C., May 14–16, 1946, and will be distributed in advance pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at the meeting registration desk.**

**Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE**

**46-101-ACO—Co-ordinated Communication System Speeds TVA Operations;** *T. D. Talmage* (*M '40*). *30 cents.* This paper outlines the development and present extent of communication and control systems used by the Tennessee Valley Authority. Intrasite manual and automatic telephone installations have been co-ordinated with various types of intersite circuits for integrated operation. Most of the intersite circuits are secured by superimposing carrier upon power lines. The carrier equipment is of three types:

1. Amplitude modulated.
2. Frequency modulated.
3. Frequency shift.

These channels furnish vital services, such as telemetering, pilot relaying, remote tripping and closing of oil circuit breakers, load-frequency control, high-speed printer telegraph, and telephony. Radio is used for rain and stream-flow gauging purposes, bridging defective sections of telephone lines, as well as two-way communication with mobile units. This paper describes the principal features of a balanced combination of modern communication facilities and services which handle 2,500,000 telephone calls a year.

## Communication

**46-102—Factors Affecting Range of Radar Sets;** *L. R. Quarles* (*M '45*), *W. M. Breazeale. 15 cents.* The type of antenna and reflector determine the energy in the projected beam and the beam width. Of the portion of this energy intercepted by an airplane, a fraction is returned to the station. The combination of the antenna and airplane factors then gives the power returned in terms of transmitted power. This received power must give enough signal-to-noise for satisfactory operation of the receiving equipment. An equation for the range of a radar set is developed by considering these various factors. This indicates that the range is proportional to the fourth root of the peak transmitted power and the fourth root of the effective reflector cross section.

## Electronics

**46-96—Maintenance of Rectifiers on Electrochemical Installations;** *J. E. Housley* (*F '43*), *G. N. Hughes* (*M '43*). *15 cents.* Operating experiences and information gained over a period of years from the operation of a large group of mercury-arc rectifiers have shown that, though the rectifier is a very economical means of converting from a-c to d-c power it is not entirely trouble free. The principal operating difficulty has been the seemingly inherent tendency for a rectifier to arc-back. This peculiarity has challenged both the designer and operator since it has been found that both contribute toward the solution. The present paper presents the features which have been found advisable for the operator to observe and control in order to keep the arc-back rate at a minimum.

## Industrial Power Applications

**46-97—Lightning Protection for Industrial Plants;** *Edward Beck* (*M '35*), *J. Z. Lissenmeyer* (*M '43*). *15 cents.* Under this subject is considered lightning protection for the buildings and for the electric circuits and equipment in the buildings. For the type of plant being considered, principally textile mills, the circuit voltage is assumed to be generally of the order of 550 volts alternating current. Power usually is supplied from a transmission or distribution system through a step-down transformer. It is assumed that the high voltage side of the transformer is protected sufficiently to assure continuity of power supply to the plant. The plant circuits themselves may be subject to lightning disturbances, depending on the degree of exposure and the degree of lightning frequency and intensity. The most vulnerable piece of equipment on the circuits is the motors. Such exposed circuits should be equipped with capacitors and arresters to safeguard the motors and other apparatus. In some cases overhead ground wires or lightning rods may be advisable also.

## Protective Devices

**46-98-ACO—Selective Ground Relaying of an Ungrounded System;** *E. P. Miller* (*M '45*). *15 cents.* This paper describes a method of providing selective ground relaying of an ungrounded delta-connected system. Essentially the scheme consists in using the system capacitance to ground in lieu of a grounding bank to supply the currents needed for the selective relays, and a set of Y-open delta potential transformers to supply a voltage with which to compare these currents. Basic formulas, applicable to any ungrounded system, are derived, and figures are substituted in the formulas showing how the method was applied to one particular problem. Brief descriptions of the relays used and of the tests made are included. It is noted that this method of protection compares very favorably both in cost and in operating characteristics with the protection afforded by a grounding bank and conventional ground relays.

# PERSONAL • • • •

**C. T. Evans** (A '11, M '20) formerly development engineer, Cutler-Hammer, Inc., Milwaukee, Wis., has been named consulting engineer. Mr. Evans was graduated from Ohio State University in 1908 and that year joined the Cutler-Hammer company as a student engineer. He then became a member of the engineering department and was one of the original members of the company's development department in 1924. In 1935 he was made supervising development engineer. During World War II he served as a member of the controller development committee of the Navy Department's Bureau of Ships. Mr. Evans is a member of the Engineers' Society of Milwaukee, the American Association for the Advancement of Science, and the International Association of Electrical Inspectors. **C. W. Kuhn** (A '23, F '39) formerly supervising engineer, development department, Cutler-Hammer, Inc., has been made

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assistant manager of development. Mr. Kuhn joined the Cutler-Hammer company in 1923 after his graduation from the University of Cincinnati as a student engineer. After two years in the experimental department he was transferred to the development department and in 1938 was made a supervising development engineer. He is a member of the American Society of Refrigeration Engineers, the American Interprofessional Institute, and the Engineers' Society of Milwaukee. **R. A. Millermaster** (M '34) formerly supervising development engineer, Cutler-Hammer company, also has been made assistant manager of development. A 1927 graduate of the University of Wisconsin, Mr. Millermaster entered the employ of the company as a student engineer. He has since been a member of the drafting, experimental, and developments departments of the company. He is chairman of the AIEE committee on aircraft electrical control and protective devices and of several committees of the National Electrical Manufacturers Association. He also is a member of the Engineers' Society of Milwaukee.

**J. W. Barker** (M '26, F '30) dean of the school of engineering, Columbia University, New York, N. Y., has resigned to become president of the Research Corporation, New York, N. Y., a foundation for the support of investigations in educational and scientific laboratories throughout the United States. Doctor Barker has been a member of the board of directors of the corporation for some time and had served on a part-time basis as acting director since January 1945. Doctor Barker, who holds the degrees of bachelor (1916) and master (1925) of science from Massachusetts Institute of Technology, entered the teaching profession there in 1925 as professor of electrical engineering. In 1929 he became professor and head of the department of electrical engineering at Lehigh University and in 1930 was appointed dean at Columbia University. From 1941 to July 1945 Doctor Barker served as special assistant to the Secretary of the Navy in charge of the Navy's educational and training programs and for this service received the Distinguished Civilian Service Award. He is a member of the advisory committee of the United States Coast Guard Academy, New London, Conn., and of the United States National Committee of the International Commission on Illumination. He also is a member of the American Association for the Advancement of Science, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the New York Electrical Society, the Newcomen Society, Sigma Xi, and Tau Beta Pi.

**Robert Paxton** (A '26, M '40) formerly manager, Philadelphia (Pa.) works of the General Electric Company, recently was appointed manager of the General Electric Pittsfield (Mass.) apparatus works. Mr. Paxton became associated with the General Electric Company after being graduated from Rensselaer Polytechnic Institute in 1923. He began in the switchboard department in Schenectady, N. Y., and later was transferred to the oil circuit breaker engineering division in Philadelphia. In 1929 he was made managing engineer of the metal enclosed division and in 1932 was named managing engineer of the panel and equipment division serving in that capacity until 1940 when he was named assistant to the manager. Mr. Paxton became manager of the Philadelphia works in 1941. **L. E. Underwood** (A '03, M '13) former manager of the Pittsfield apparatus works, has retired. Mr. Underwood was graduated from the Sheffield Scientific School of Yale University in 1896 and, after 1½ years with the Brainard Milling Machine Company, entered the stationary motor engineering department of the General Electric Company, Lynn, Mass., in 1899. In 1915 Mr. Underwood was made chief engineer, and in 1927 he was appointed managing engineer of the consolidated motor department in charge of engineering and manufacturing. He became manager of the Pittsfield works in 1932.

**Constantine Bary** (A '25, M '43) rate research engineer, Philadelphia (Pa.) Electric Company, has been awarded the AIEE Philadelphia Section best initial paper prize for the year 1945–46 for the paper on "Coincidence Factor Relationships of Electric-Service-Load Characteristics" (*AIEE Trans., vol 64, 1946, Sept sect, pp 623–9*). Born December 26, 1903, in St. Petersburg, Russia, Mr. Bary was graduated from the Massachusetts Institute of Technology in 1927 with the degree of bachelor of science in electrical engineering. Since 1922 he has been associated continuously with the Philadelphia Electric Company, Philadelphia, Pa. During World War II he served as consultant to the Office of Production Management, as chief of power requirements and forecasts of the War Production Board, as consulting power engineer of the Office of War Utilities, and as consultant on the staff of the Technical Industrial Disarmament Committee for the German electric power industry under the auspices of the Foreign Economic Administration.

**C. E. Stryker** (A '21, F '35) formerly vice-president and assistant to the president, Nordberg Manufacturing Company, Milwaukee, Wis., has been elected president and general manager of Adel Precision Corporation, Burbank, Calif. Mr. Stryker holds the degrees of bachelor of science in electrical engineering (1917) and electrical engineer (1924) from the Armour Institute. He commenced his career in Chicago, Ill., where he was testing engineer for the Commonwealth Edison Company in 1917, engineer and purchasing agent for the Ozone Pure Airifier Company in 1919, and assistant engineer for the Underwriters Laboratories in 1922. In 1923 he was named electrical engineer by Fansteel Products Company, Inc., North Chicago. He subsequently became manager of the industrial division, vice-president and general manager of the Ramet Corporation of America, a Fansteel subsidiary, and chief engineer of the Fansteel company. He joined the firm of McKinsey, Kearney and Company in 1933 and became a partner in 1938. He has been associated with the Nordberg company since 1940. Mr. Stryker is a member of the Society of Automotive Engineers, the American Society of Naval Engineers, the Engineers' Society of Milwaukee, and the Newcomen Society. From 1920 to 1924 he was assistant professor of electrical engineering at the Armour Institute.

**W. J. Shackleton** (A '12) development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has retired. Mr. Shackleton was graduated from the University of Michigan with the degree of bachelor of science in 1909 and immediately joined the Western Electric Company, Hawthorne, Ill. He was transferred to the physical laboratory in New York in 1910 as development engineer and continued with Bell Laboratories when they were established in 1925. In 1928 he was appointed transmission apparatus engineer. His studies in the application of magnetic materials and refinements in the art of precision electrical measurements of impedance, time, and frequency have had nation-wide recognition. During World War II, he had charge of important projects for the United States Navy concerning the development of magnetic devices for various applications, including the detection of submerged magnetic bodies. He also was appointed a consultant by the National Defense Research Council. Mr. Shackleton has served on committees of the American Society for Testing Materials and the American Standards Association.

**J. K. Johnson** (A '28) formerly executive engineer, Hammarlund Manufacturing Company, New York, N. Y., has opened an office for radio and electronic engineering consulting services in New York. He received the degree of electrical engineer from Columbia University in 1927 and was an instructor in physics at Mechanics Institute, New York, from 1925 to 1929 and an instructor in electrical engineering at Columbia University in 1928 and 1929. Dur-

ing the latter years he was chief research engineer for the Pacent Electrical Corporation, New York, and was assistant chief engineer for Silver-Marshall, Chicago, Ill., in 1929 and 1930. He was an engineer with the Hazeltine Corporation, New York, from 1930 until in 1934 he returned to Chicago as chief engineer of the Wells Gardner Company. He took charge of the Chicago laboratory of the Hazeltine Service Corporation in 1937. He was named chief of production section, electronics division, Office of the Secretary of the Navy, Washington, D. C., in 1943 and joined the Hammarlund company in 1944.

**J. D. Mamarchev** (M '45) formerly chief engineer, The Austin Company's Freeport, Tex., office, has organized the consulting firm of James D. Mamarchev and Associates, Houston, Tex. Mr. Mamarchev holds degrees from the Sofia State Lyceum, Sofia Military College, the University of Manchester, and Columbia University. From 1923 to 1933 he was assistant electrical engineer with Gibbs and Hill, Inc., New York, N. Y., and in 1934 became electrical engineer for the Radio Corporation of America in London, England. He was engineer in charge of the New York office of the Steinholz Engineering Company from 1935 to 1937 and for the following two years was associated with the construction of the La-Guardia Municipal Airport in New York as assistant chief and chief electrical engineer. From 1940 to 1944 he was associated for brief periods with the United States Engineers' Corporation; Robert and Company, Atlanta, Ga.; Basic Magnesium, Inc., Las Vegas, Nev.; Donald R. Warren Company, Los Angeles, Calif.; and the United States Navy Yard, Mare Island, Calif. In 1944 he joined the Austin company.

**M. H. Pratt** (M '34) formerly electrical engineer, engineering department, Central New York Power Corporation, Syracuse, has been appointed chief engineer of the corporation. Mr. Pratt entered the employ of the Niagara Hudson system as a cadet engineer with the Syracuse Lighting Company in 1926, the year he was graduated from the University of Pennsylvania. In 1927 he was first assistant to the distribution engineer and then assistant distribution engineer, and in 1928 assistant engineer and then engineer of the electrical department. He was appointed assistant division engineer for the central division of the Niagara Hudson system in 1931 and division engineer in 1932. When the Central New York Power Corporation was formed in 1937, he became electrical engineer. He is a member of Sigma Xi and Tau Beta Pi.

**W. V. B. Van Dyck** (A '01, M '31) assistant to the president, International General Electric Company, Schenectady, N. Y., has retired. Mr. Van Dyck holds the degrees of bachelor of science and master of science from Rutgers College and electrical engineer from Columbia University. From 1897 to 1899 he was employed by the American Luxfer Prism Company, Chicago, Ill., and for one year afterwards was instructor at Rutgers College, New Brunswick, N. J. After a period as a consulting engineer he worked for W. R. Grace and Company in Valparaiso and Santiago, Chile, from 1907 to 1911. In 1911 he joined the General Electric Company in Rio de Janeiro, Brazil, becoming managing director and president of the South American company. He was appointed manager of the International General Electric Company's Schenectady office in 1927 and assistant to the president in 1937.

**J. S. Moulton** (A '22, M '27) formerly commander, Civil Engineer Corps, United States Naval Reserve, Berkeley, Calif., has been named executive engineer of the Pacific Gas and Electric Company, San Francisco, Calif. Mr. Moulton was graduated from Sheffield Scientific School of Yale University in 1920, and entered the operating department of the San Joaquin (Calif.) Light and Power Company. Following that he joined the Great Western Power Company, becoming executive engineer in 1929, and, when in 1930 that company merged with the Pacific Gas and Electric Company, he was made assistant to the vice-president and general manager. In 1940 he was transferred to the executive engineer's department. He entered the Navy in 1942 as a lieutenant commander.

**Paul Crago** (A '44) formerly railroad representative, general commercial department, Federal Telephone and Radio Corporation, Newark, N. J., will be supervisor of the new New York, N. Y., branch laboratory of the Wilmotte Laboratory, Inc., Washington, D. C. Mr. Crago previously was associated with the Union Switch and Signal Company, and Specialties, Inc. **G. C. Engel** (A '41) formerly production manager of General Electronics, Inc., and manager of the laboratory of General Time Instruments Corporation, New York, will head a group specializing in electronic controls and inspection methods. Mr. Engel was graduated from Stevens Institute of Technology in 1927.

**F. L. Nason** (A '43) formerly New England district manager, Westinghouse Electric Corporation, Boston, Mass., has been made a special representative of the company in the New England district. Mr. Nason joined the Westinghouse corporation in 1914, was made central station sales manager in 1921, and district sales manager in 1938. He recently was elected president of the Electric Institute of Boston. **F. S. Bacon** (A '37, M '44) formerly assistant manager of the central station division for the district, has been made central station manager. Mr. Bacon was graduated from Northeastern University and joined the Westinghouse corporation in 1936. He has been assistant manager since 1941.

**W. S. Gifford** (A '16) president, American Telephone and Telegraph Company, New York, N. Y., has been awarded the Medal for Merit of the United States. The citation accompanying the award states that Mr. Gifford "made every effort to assure that the facilities of his organization were utilized to the maximum extent possible in the successful prosecution of the war. Under his direction and leadership radio teletypewriter systems were developed. . . . Not only did Mr. Gifford place the technical facilities of his company at the disposal of the Army, but he directed it in playing a major role in furnishing highly trained technical specialists to the Army through the affiliated plan."

**J. C. Arnell** (A '28) formerly manager, personnel co-ordination bureau, Consolidated Edison Company of New York (N. Y.), Inc., has been appointed senior assistant personnel director.

**H. F. Lowe** (A '33) formerly chief of the materials control section of the Office of War Utilities, Washington, D. C., has become a partner in the firm of Sloan and Cook, Chicago, Ill.

**R. C. Mildner** (A '34) formerly squadron leader in the Royal Air Force, has joined the technical staff of the Telegraph Construction and Maintenance Company, Ltd., England.

**Llewellyn Evans** (A '07, F '41) chief consulting engineer, Tennessee Valley Authority, Chattanooga, Tenn., has been loaned to the War Department and will be sent to Austria to assist the government on problems of power generation and distribution.

**A. G. L. McNaughton** (A '11, HM '42) former commander in chief of the Canadian Army and later Minister for National Defense, has been appointed Canadian representative on the United Nations' Atomic Energy Commission.

**F. H. Ferguson** (A '34, M '42) power and light superintendent, Bremerton (Wash.) division of the Puget Sound Power and Light Company, has been transferred to the central division, Seattle.

**C. W. Kellogg** (A '19, M '23) president of the Edison Electric Institute, New York, N. Y., will retire June 30. Mr. Kellogg has held his present position since 1939.

**C. O. Jett.** (A '42, M '44) formerly radar engineer, United States War Department, Washington, D. C., has been appointed system telegraph and telephone engineer for the Union Pacific Railroad, Omaha, Nebr. Mr. Jett attended the University of Kentucky, Eastern Kentucky State Teachers' College, and George Washington University. Before the war he was associated with the Bell Telephone System, the United States Forest Service, and the Tennessee Valley Authority.

**W. B. Bedell** (A '35, M '35) has returned to the long lines engineering department of the American Telephone and Telegraph Company, in New York, N. Y., after having served as district engineer of the long lines plant department in Chicago, Ill., since 1940. Mr. Bedell entered the employ of the American Telephone and Telegraph Company in the long lines department in 1919 after short periods with the General Electric Company, Schenectady, N. Y.; the B. F. Goodrich Rubber Company, Akron, Ohio; and the Truscon Steel Company, Youngstown, Ohio.

**J. E. Smith** (A '39) formerly senior research engineer, terminal facilities department, RCA Laboratories, Radio Corporation of America, New York, N. Y., has become head of the microwave communication engineering department of the Raytheon Manufacturing Company, Waltham, Mass. Mr. Smith is a graduate of Jamestown College and received the degree of master of electrical engineering from California Institute of Technology in 1933. He joined the Radio Corporation of America in 1934 as student engineer and was instructor in the RCA Institute for four years and a graduate lecturer at New York University for three. In 1938 he became engineer in the central office laboratory. At present he is adjunct professor at the university. He is a member of the Institute of Radio Engineers.

**D. L. Jaffe** (A '36) formerly chief research engineer, Templetone Radio Company, Mystic, Conn., has joined the Polarad Electronics Company, New York, N. Y., as a partner and general manager. Doctor Jaffe received the degrees of bachelor of science from the College of the City of New York in 1935, master of science in 1936, and doctor of philosophy from Columbia University in 1940. From 1937 to 1939 he was occupied with research in frequency modulation at Columbia University, New York, and in 1939 became television engineer for the Columbia Broadcasting System. He was appointed development engineer in the microwave radar division of the Raytheon Manufacturing Corporation, Waltham, Mass., in 1942 and in 1944 joined the staff of the Templetone company. He also is a member of Sigma Xi and the Institute of Radio Engineers.

**A. A. Sylvane** (A '35, M '42) formerly chief engineer, Commercial Radio and Sound Corporation, New York, N. Y., is now chief engineer of Continental Electronics, Ltd., New York. Mr. Sylvane, who was born in Brooklyn, N. Y., in 1913, was graduated from the College of the City of New York with the degree of bachelor of science in 1934 and in 1935 received the degree of electrical engineer. He has been associated with the Commercial Radio corporation since 1935 designing and engineering large centralized sound and public address systems and special systems for teaching the hard of hearing. During 1939 and 1940 Mr. Sylvane was in charge of all communication and public address work at the New York World's Fair.

**C. E. Egeler** (M '41) captain in the United States Naval Reserve, has returned to the engineering division of the General Electric Company, Cleveland, Ohio. Since his return he has been assigned to federal government lighting activities and research on industrial applications of infrared applications. Captain Egeler, who also served in World War I, was called to active duty as a lieutenant commander in 1941. He served as resident inspector of Navy material and director of the Munhall Navy Laboratory in the Pittsburgh district and as head of the Naval Inspection Service in the Pittsburgh area.

**W. M. Adler** (A '25, M '44) engineer on war leave of absence from the Consolidated Edison Company of New York (N. Y.), Inc., has resigned as electrical engineer of the repairs and utilities section, military construction division, Office of the Chief of Engineers, Washington, D. C., to return to the Edison company. Mr. Adler left the company in 1942 to become electrical engineer for the National Housing Administration's Fairlington project in Arlington, Va. When this was completed in 1944, he joined the Office of the Chief of Engineers.

**E. I. Pease** (A '21, M '29) formerly principal engineer, Civil Works Branch, United States Engineering Office, Seattle, Wash., has been appointed head of the engineering division of the Seattle District of the United States Army Engineers. Mr. Pease has been with the United States office since he was graduated from the University of Washington in 1912. Since 1928 he has served in executive capacities connected with comprehensive surveys of regional water resources, improvement of waterways and harbors, and projects for flood control.

**C. S. Lumley** (A '23, F '45) formerly industrial engineering manager and chief industrial engineer, Smith, Hinchman, and Grylls, Inc., engineers and architects, Detroit, Mich., and New York, N. Y., has been made industrial division manager of the company. Mr. Lumley first became associated with the company in 1925 as electrical engineer. From 1940 to 1944 he was with the Roller-Smith Company, Bethlehem, Pa., as district engineer and later general manager, returning to the Detroit office of Smith, Hinchman, and Grylls in 1944 as industrial engineering manager.

**L. L. Glezen** (A '22, M '29) telephone engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has been awarded the Bronze Star Medal for outstanding service in support of combat troops. Mr. Glezen was a technical observer for the Signal Corps in England and on the continent. He was commended for working for periods of 24 to 36 hours of his own volition in order to restore French telephone facilities for military use in the crucial days of the Normandy invasion and after the liberation of Paris.

**Morton Sultzer** (A '13, M '34) until recently on leave of absence from Bell Telephone Laboratories, Inc., New York, N. Y., and colonel, United States Signal Corps, has been awarded the Legion of Merit. Colonel Sultzer has served as chief of the Stock Control Division, Storage and Issue Agency and as commanding officer of the Sacramento Signal Depot. Colonel Sultzer was commended for innovations which greatly reduced the processing time required for requisitions for equipment from United States troops.

**J. W. Koch** (A '35) formerly captain, United States Army, has joined the engineering staff of the Mutual Broadcasting System. Since 1942 he served variously as technical adviser of the Radio Propaganda Unit, staff radio officer at Allied Force Headquarters in North Africa and Italy, and in the office of the Chief Signal Officer in Baltimore, Md. Mr. Koch, a 1934 graduate of the University of Nebraska, previously had been associated with station KFEQ, St. Louis, Mo.

**Joseph Bronaugh** (A '29, M '37) formerly sales representative, Allis-Chalmers Manufacturing Company, Richmond, Va., has been appointed manager of the company's newly established branch office in Miami, Fla. A 1927 graduate of the University of Virginia, Mr. Bronaugh joined the Allis-Chalmers company in 1929. During World War II he served as a lieutenant in the United States Naval Reserve for 31 months.

**T. W. Eadie** (A '27) general plant manager, Bell Telephone Company of Canada, Toronto, Ontario, has been transferred to Montreal, Quebec, as assistant vice-president. Mr. Eadie joined the company after his graduation from McGill University in 1923. He became toll and transmission engineer in 1927, division plant engineer in 1929, and outside plant engineer in 1930. In 1936 he was made general plant superintendent, and general plant manager in 1939.

**D. S. Smith** (A '33) wartime power research engineer, physics and electrical engineering department, National Research Council, Ottawa, Ontario, Canada, has rejoined the Northern Electric Company as power apparatus sales engineer in the company's Vancouver, British Columbia, office. Mr. Smith is a graduate of the University of British Columbia and has been with the Northern Electric Company since 1936.

**W. L. Mann** (A '03) division manager, Metropolitan Edison Company, York, Pa., has retired. Mr. Mann received the degrees of bachelor of science from Virginia Polytechnic Institute in 1901 and mechanical engineer from Cornell University in 1903. He became general manager of the York Haven (Pa.) Water and Power Company in 1911 and continued as local manager when the company was purchased by the Metropolitan Edison Company in 1923. In 1926 he was made division manager.

**G. E. Snider** (A '17, F '39) formerly vice-president and general distribution engineer, Ohio Public Service Company, Cleveland, has been named vice-president in charge of operations for the company. Mr. Snider started his career in 1905 with the Toledo Railway and Light Company, continuing with design and construction work when this company became the Toledo Edison Company. In 1922 he joined the Ohio Public Service Company as general distribution engineer, and as such he designed the company's 132-kv transmission system. In 1927 he organized the company's safety program and in 1941 was appointed vice-president.

**C. E. Hastings** (A '36, M '43) formerly physicist, research department, National Advisory Committee for Aeronautics, Langley Field, Va., has been appointed chief engineer, Hastings Instrument Company, Hampton, Va. Mr. Hastings received a bachelor of engineering degree from Johns Hopkins University in 1935 and engaged in advance study at the University of Virginia. During the war he taught in the University of Virginia Extension Division. He had been with the National Advisory Committee for the past ten years.

**W. W. Satterlee** (A '23, M '41) division engineer in the small power and network division, Westinghouse Electric Corporation, Sharon, Pa., and **Saul Bennon** (A '38) project engineer in the Sharon plant, have been awarded the Westinghouse Order of Merit. Mr. Satterlee was cited for his ability in developing and marketing the ASL dry type power transformer, and Mr. Bennon for his part in the design, development, and manufacture of a new electric torpedo.

**I. G. Easton** (A '41) engineer, General Radio Company, Cambridge, Mass., has been appointed manager of the company's New York, N. Y., engineering and sales office. Mr. Easton holds degrees from Northeastern and Harvard Universities and has been with the General Radio Company since 1939. He also taught wartime courses in radio engineering at Northeastern University.

**A. W. Walton** (A '39, M '45) protective engineer, relay department, Oklahoma Gas and Electric Company, Oklahoma City, has been appointed electrical engineer, generation department. Mr. Walton joined the company in 1928 and has been protective engineer since 1935. **G. E. Brooks** (A '41) formerly relay engineer, succeeds Mr. Walton as protective engineer. Mr. Brooks has been with the company since 1935.

**R. S. Plotz** (A '38, M '45) formerly member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed assistant to vice-president. Mr. Plotz, a graduate of the University of Wisconsin, joined the laboratories in 1930.

**F. M. Tait** (A '94, F '12) president and general manager, Dayton (Ohio) Power and Light Company, has resigned from these two offices but will remain as chairman of the board of the company. Mr. Tait, who was born in Catasauqua, Pa., in 1874, was associated early in his career with the Catasauqua Electric Light and Power Company, the Somerset Lighting Company in New Jersey and the New London (Conn.) Gas and Electric Company. He joined the Dayton Electric Light Company, predecessor of the Dayton Power and Light Company, in 1905 as manager and director.

**R. D. Bennett** (F '35) captain, United States Naval Reserve, and director of technical development, Naval Ordnance Laboratory, Washington, D. C., recently was presented with the Legion of Merit in recognition of his services at the laboratory since 1940. The citation lauds his "thorough knowledge of theoretical and applied sciences . . . his administrative ability in the field. . . . His discerning efforts in the fulfillment of an assignment vital to the successful prosecution of the war. . . ." The British Government recently made Captain Bennett an Honorary Officer of the Military Division of the Most Excellent Order of the British Empire.

**H. C. Madsen** (A '42) manager, university relations, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed manager of industrial relations, Bryant Electric Company, Bridgeport, Conn. Mr. Madsen previously was connected with the Philco Radio and Television Corporation, Philadelphia, Pa.

**Reinhold Rüdenberg** (M '38) Gordon McKay professor of electrical engineering, Harvard University Graduate School of Engineering, Cambridge, Mass., recently received one of the three Honor Awards of the Alumni Association of Stevens Institute "for notable achievement in the field of electron optics, as the inventer of the electron microscope."

**C. L. Johnson** (A '46) member of the sales staff in the Dugas office, Chicago, Ill., of the Ansul Chemical Company, has been appointed manager of that office. Mr. Johnson previously had been connected with the Sherwin-Williams Company, the La Salle Steel Company, and the Republic Steel Corporation.

**A. R. Stevenson, Jr.** (A '20, F '37) vice-president in charge of engineering policy, General Electric Company, Schenectady, N. Y., recently received the honorary degree of doctor of engineering from Stevens Institute of Technology.

**G. H. Bucher** (M '24) who recently resigned as president of the Westinghouse Electric Corporation, Pittsburgh, Pa., has been elected vice-chairman of the board of directors of the company.

**W. C. Morrison** (A '44) formerly supervisor of the electrical operations department for the Carbide and Carbon Chemical Corporation, at the atomic bomb project, Oak Ridge, Tenn., has joined the staff of the industrial engineering department of the Iowa–Illinois Gas and Electric Company, Moline, Ill. Mr. Morrison was graduated from the University of Iowa in 1942 and previously was associated with the General Electric Company, Schenectady, N. Y.

**G. G. Jones** (M '35) formerly general plant superintendent of the central area, long lines department, American Telephone and Telegraph Company, is now general plant superintendent of the Eastern area. **R. H. Ross** (M '25, F '43) division plant superintendent, long lines department, Philadelphia, Pa., has been appointed general plant superintendent of the central area.

**V. E. Schlossberg** (A '29, M '35) assistant superintendent of electric and power departments, Inland Steel Company, East Chicago, Ind., has been elected a director of the Association of Iron and Steel Engineers. Mr. Schlossberg was a member of the technical group which went to Germany in 1945 to investigate the steel industry.

**J. E. Underhill** (A '29, M '37) formerly lieutenant colonel, assistant director of research, Royal Canadian Artillery, Canadian Active Service Forces, Ottawa, Ontario, has returned to the British Columbia Electric Railway Company, Vancouver, and has been appointed director of the industrial development department. Mr. Underhill had been with the company from 1927 until he entered military service in 1940. Early in his career Mr. Underhill was associated with the Canadian Westinghouse Company, as well as with the Westinghouse Electric Corporation, Pittsburgh, Pa.

**H. S. Osborne** (A '10, F '21) chief engineer, American Telephone and Telegraph Company, New York, N. Y., recently was awarded a fellowship in the Institute of Radio Engineers for his "contributions in the electrical communication field including outstanding leadership and direction in the application of new techniques to telephony."

**W. A. Perry** (M '38) formerly superintendent of the electrical and power departments, Inland Steel Company, East Chicago, Ind., has been made assistant to the general superintendent of the company. Mr. Perry has been with the company since 1910 and is a past president of the Association of Iron and Steel Engineers.

**L. R. Milburn** (A '20, F '39) electrical engineer, Great Lakes Steel Corporation, Ecorse, Mich., has been elected first vice-president of the Association of Iron and Steel Engineers.

**G. V. Harrap** (A '34, M '43) formerly deputy city electrical engineer of Norwich, Norfolk, England, has been appointed borough electrical engineer and manager by the Council of Gravesend, Kent. Mr. Harrap previously was associated with the West Ham, Hill, and Dundee Electricity Departments, the North-Eastern Electricity Supply Company, Ltd., and the Metropolitan-Vickers Electrical Company, Ltd.

**C. E. Dreher** (A '43) regional director of Brazil, Westinghouse Electric International Company, Rio de Janiero, has been awarded the Westinghouse Order of Merit "for outstanding performance in the establishment and expansion of the company's business performance in foreign territory under exceptional circumstances."

**R. H. Mecklenburg, Jr.** (A '42) recently lieutenant in the Army Signal Corps, has returned from two years of European service to resume his former position of instrumentation specialist with the Automatic Temperature Control Company, Inc., Philadelphia, Pa. He is a graduate of Drexel Institute of Technology.

**J. H. Blankenbuehler** (A '31, M '40) section engineer, welding engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been made manager of arc welding apparatus for the corporation. Mr. Blankenbuehler was graduated from Lehigh University in 1923 and has been with the Westinghouse corporation since.

**Vance Oathout** (A '30) chief engineer, Indiana Bell Telephone Company, Indianapolis, has retired. Mr. Oathout was born in Luana, Iowa, in 1881. He entered the employ of the Bell Telephone System in 1903 and spent his entire engineering career with the company. From his first position of groundman he advanced to lineman, foreman, wire chief, exchange manager, traffic superintendent, plant extension engineer, and finally to chief engineer.

**R. W. Gemmell** (M '43) formerly manager of the aviation section, industrial engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has become manager of the corporation's aircraft sales department, Lima, Ohio. Mr. Gemmell was graduated from the University of Minnesota in 1926, the year he joined the Westinghouse corporation. He has been working on aviation problems since 1936.

**J. C. Henkle** (M '36) formerly assistant general superintendent, Portland (Oreg.) General Electric Company, has been appointed general superintendent. Mr. Henkle, who has been with the company 37 years, commenced his career as a wireman, later becoming foreman and superintendent of electrical maintenance and construction. He has been assistant general superintendent since 1943.

**J. H. Cox** (A '25) formerly section engineer, mercury arc rectifier engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed engineering manager for the Pacific Coast manufacturing and repair division headquarters, Emeryville, Calif. Mr. Cox joined the Westinghouse corporation in 1923 as service engineer and has been section manager since 1930.

**Maurice Holland** (A '23, M '30) industrial research adviser, New York, N. Y., has been named director of the Scandinavian Industrial Survey, which will provide for a group of American leaders to visit Scandinavia. The Survey is the outgrowth of an invitation from **E. E. Velander** (A '18, M '44) director, Royal Swedish Institute for Scientific Engineering Research, Stockholm. Mr. Holland recently was elected first honorary fellow of the Industrial Research Institute, Inc.

**Gerard Swope** (A '99, F '22) honorary president, General Electric Company, Schenectady, N. Y., recently received the gold medal award of the American Society for Metals for his accomplishments in promoting research for the increased use of metals.

## OBITUARY

**Samuel Bingham Hood** (M '14) development and research engineer, San Leandro, Calif., died March 9, 1946. Mr. Hood was born in Philadelphia, Pa., July 12, 1875. After a brief period as an independent contractor, Mr. Hood was associated early in his career with the Berliner Gramaphone Company; the Diamond Electric Light Company, Philadelphia; the Egg Harbor Electric Light and Power Company and the Gloucester County Electric Company, both in New Jersey; and the Powelton Electric Company in Pennsylvania. From 1900 to 1906 he was with the Philadelphia Electric Company as station lineman, district superintendent of construction, and assistant engineer of distribution and construction. After a two-year period as an electrical contractor, he joined the Toronto Electric Light Company, Ltd., Ontario, Canada, as distribution engineer, later becoming superintendent of distribution. In 1917 he became associated with the Northern States Power Company, Minneapolis, Minn., as distribution engineer and in 1918 was made superintendent of distribution. He retired in 1927 as consulting engineer to the company. Since that time he was retained as a consultant by The James R. Kearney Corporation, St. Louis, Mo. He was the author of articles appearing in *Electrical World*.

**Kiron Chandra Roy** (A '31) managing director, Oriental Mercantile Company, Ltd., and technical director, Bengal Electric Lamp Works, Ltd., both of Calcutta, India, died October 19, 1945. Mr. Roy was born December 23, 1903, in Narayanganj, Dacca, Bengal, was graduated from Bengal Technical Institute in 1926, and received the degree of bachelor of science from Massachusetts Institute of Technology in 1929. For a period he was testman with the General Electric Company, Lynn, Mass. In 1935 he was appointed sales manager for the Bengal Electric Lamp Works, Ltd., Calcutta, and in 1938 managing director of the Oriental company. He assumed the additional duties of technical director of the Bengal Lamp company in 1939. Since 1941 he had been executive head of the College of Engineering and Technology, Bengal. He served as a member of the Electric Licensing Board of the Government of India and on several panels of its Planning and Development Department. Since 1943 he had been chairman of the electric lamp manufacturers' advisory panel to the Director General of Munition Production.

**Norman Allen Rollins** (M '27, F '40) retired staff engineer, Commonwealth Edison Company, Chicago, Ill., died February 6, 1946, in Manchester, N. H. Mr. Rollins was born in Portsmouth, N. H., March 6, 1878, and was graduated from New Hampshire College in 1901. After completing the student course at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he commenced his association with the Commonwealth Edison Company in 1904 as design engineer. In 1906 he was given supervision of architects and contractors on installation work and in 1916 was named engineer in charge of electrical design. From 1917 to 1932 he supervised the installation of large industrial substations and in 1932 was titled plant installation engineer. He retired in 1944 as staff engineer.

## MEMBERSHIP

### Recommended for Transfer

The board of examiners, at its meeting of April 18, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

#### To Grade of Fellow

Bennett, R. S., chief elec. engr., T. Firth, J. Brown, Ltd., Sheffield, England

Garman, C. P., chief elec. engr., deputy gen. mgr., power system, Dept. of Water & Pr., City of Los Angeles, Calif.

Harte, C. R., engr., Connecticut Co., New Haven, Conn.

Lee, C., prof. of elec. engr., Virginia Polytechnic Institute, Blacksburg, Va.

McCreary, H. J., electronics engr., Automatic Elec. Co., Chicago, Ill.

West, G. B., chief engr., Illinois Bell Telephone Co., Chicago, Ill.

6 to grade of Fellow

#### To Grade of Member

Barber, C. D., primary meter man, Oklahoma Gas & Elec. Co., Enid, Okla.

Behn, E. R., senior engr., U. S. Navy Dept., Bureau of Ordnance, Washington, D. C.

Davis, D. W., Comdr., USNR, instructor in elec. engg., radio & electronics, U. S. Naval Academy, Annapolis, Md.

Diefenbach, L. T., starting engr., gr. grade, Commonwealth Edison Co., Chicago, Ill.

Dingle, R. L., elec. engr., Air Technical Service Command, AAF, Wright Field, Dayton, Ohio

Dunlap, L. B., engr., Southwestern Bell Telephone Co., Dallas, Tex.

Dyche, H. E., Jr., engr., Westinghouse Elec. Corp., East Pittsburgh, Pa.

Farris, W. A., elec. engr., U. S. Engineer Office, Cincinnati, Ohio

Fritschel, P. G., supervisor of field engg., test & inspection, General Elec. Co., Syracuse, N. Y.

Gamey, W. A., application engr., Westinghouse Elec. International Co., New York, N. Y.

Hansen, E. L., maintenance engr., Community Public Service Co., Fort Worth, Tex.

Heumann, G. W., engr., General Elec. Co., Schenectady, N. Y.

Hodgson, A. O., sr. elec. engr., U. S. Naval Dry Dock, So. Boston, Mass.

Holmgren, E. L., dev. engr., Kuhlman Elec. Co., Bay City, Mich.

Kanouse, E. L., trans. system engr., Dept. of Water & Pr., City of Los Angeles, Calif.

Kearns, J. J., jr. maint. engr., N.Y.C. Board of Transportation, New York, N. Y.

Laughlin, J. D., jr. elec. engr., Dept. of Water & Pr., City of Los Angeles, Calif.

Mattingly, R. L., Bell Telephone Labs., Inc., Whippany, N. J.

McNary, C. F., elec. testing engr., Commonwealth Edison Co., Pekin, Ill.

Nesmith, J., 2nd, engr., Public Service Elec. & Gas Co., Newark, N. J.

Neubauer, L. P., acting div. engr., Consolidated Edison Co. of New York, Inc., New York, N. Y.

Osterberg, E. T., sr. engr., Illinois Bell Telephone Co., Chicago, Ill.

Palmer, R. J., field engr., Municipal Lighting, Detroit Edison Co., Detroit, Mich.

Peek, H. L., engr., Allis-Chalmers Mfg. Co., Boston, Mass.

Perry, F. R., research engr., Metropolitan-Vickers Elec. Co., Ltd., Manchester, England.

Pfeifer, H. P., factory representative, Allis-Chalmers Mfg. Co., El Salvador, C. A.

Randall, E. W., Jr., in charge, elec. dept., Du Pont Experiment Station, Wilmington, Del.

Rus, J. C., designing engr., General Elec. Co., Pittsfield, Mass.

Silvius, W. P., design engr., Westinghouse Elec. Corp., E. Pittsburgh, Pa.

Spaulding, J. G., treasurer, Spaulding Elec. Co., Detroit, Mich.

Trbovich, N., chief test engr., Inland Steel Co., East Chicago, Ind.

Villar, F. B., engr., western div., Gould Storage Battery Corp., Los Angeles, Calif.

Watkins, B. D., head, operating problems unit, Rural Electrification Adm., Washington, D. C.

Weber, V. D., engr., Oklahoma Gas & Elec. Co., Enid, Okla.

White, C. H., Major, Electricity Supply Dept., Singapore, S. S.

Wyman, B. W., section leader of engg., General Elec. Co., Philadelphia, Pa.

Zimmann, S. E., project engr., Chrysler Corp., Detroit, Mich.

37 to grade of Member

## Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before June 15, 1946, or August 15, 1946, if the applicant resides outside of the United States or Canada.

### To Grade of Member

Ainsworth, C. D. (Re-election), Allis-Chalmers Mfg. Co., Hyde Park, Mass.

Beals, A. T., Advance Elec. & Relay Co., Los Angeles, Calif.

Bell, G. A., The Hydro-Elec. Power Comm. of Ontario, Toronto, Ont., Canada

Bishop, E. A., Commonwealth Edison Co., Chicago, Ill.

Boltz, H. A., The Detroit Edison Co., Detroit, Mich.

Campani, L. M., The Liquidometer Corp., Long Island City, N. Y.

Cargill, R. E., Gulf States Utilities Co., Beaumont, Tex.

Chopra, M. L., The Rawalpindi Elec. Power Co., Ltd., Rawalpindi, India

Christlieb, A. R., Public Service Co. of N. H., Manchester, N. H.

Couch, R. F., U. S. Engineers, San Francisco, Calif.

Erdelyi, E., F/L., RAFVR, Royal Aircraft Establishment, Farnborough, England

Ghose, K. K., Bairampur Raj Elec. Supply Dept., Gonda, U. P., India

Glaze, F. S., The Dow Chemical Co., Freeport, Tex.

Hartle, W. G., General Elec. Company, Philadelphia, Pa.

Hill, J. W., C. T. Gibbs, Consulting Engineer, Los Angeles, Calif.

Hinsom, P. M., American Cyanamid & Chemical Corp., Bridgeville, Pa.

Hoffman, E. R., City of Seattle, Seattle, Wash.

Hoffmann, H. W., American Cable and Radio Corp., New York, N. Y.

Hughes, D. F., Potomac Elec. Power Co., Washington, D. C.

Iyengar, K. R. R., M/S Kaycee Industries, Ltd., Lahore, India

Jernigan, P. I., Laramore & Douglass, Inc., Chicago, Ill.

Johnson, F. B., Westinghouse Elec. Corp., East Pittsburgh, Pa.

Kagawala, A., 69 West 38th Street, New York, N. Y.

Kazar, D. E., Kiefer Elec. Supply Co., Peoria, Ill.

Keck, A., Sperry Gyroscope Co., Inc., Garden City, L. I., N. Y.

Knopf, K. K., Oliver B. Lyman, Mfgrs. Representative, San Francisco, Calif.

Krasin, K. A., Chicago Bridge and Iron Co., Chicago, Ill.

Kundtz, R. H., Community Public Service Co., Ft. Worth, Tex.

Lamperty, L., Creole Petroleum Corp., Maracaibo, Venezuela, S. A.

Latham, F. A., City of Los Angeles Dept. of Water & Power, Boulder City, Nev.

Lehman, C. H., Westinghouse Elec. Corp., San Antonio, Tex.

Levstik, J. A., Chicago Bridge and Iron Co., Chicago, Ill.

Livermore, W. N., E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

Marshall, J. A., Stanley Engineering Co., Winchester, Ill.

Marysael, G. J. C., The Mexican Light & Power Co., Ltd., Mexico, D. F., Mex.

McDonnell, H. E. (Re-election), Ebasco Services, Inc., of New York City, c/o Dallas Power & Light Co., Dallas, Tex.

Miller, H. L., General Elec. Co., Chicago, Ill.

Norton, H. A., Western Union Tel. Co., Denver, Colo.

O'Keeffe, G. W., Allis-Chalmers Mfg. Co., Hyde Park, Mass.

Parks, E., Albina Eng. & Mach. Wks., Portland, Oreg.

Pinkham, H. P., Allis-Chalmers Mfg. Co., Hyde Park, Mass.

Pulver, R. F., Minnesota Power and Light Co., Duluth, Minn.

Ramsaur, O., Penna. Power & Light Co., Allentown, Pa.

Robbins, R. G., Hubbard & Co., Pittsburgh, Pa.

Robinson, E. W., Alabama Power Co., Birmingham, Ala.

Ruby, E. C., Pennsylvania Power Co., New Castle, Pa.

Sandin, J., Westinghouse Elec. Corp., E. Pittsburgh, Pa.

Scott, R. F., Southwestern Gas & Elec. Co., Shreveport, La.

Simson, G. F., Hydro-Elec. Power Comm. of Ontario, Toronto, Ontario, Canada

Sinclair, C. G., Jr., American Tel. and Tel. Co., New York, N. Y.

Skifter, H. R., Airborne Instrument Laboratory, Inc., Mineola, N. Y.

Smith, S. R., Jr., General Elec. Co., Pittsfield, Mass.

Smith, W. M., Consumers Power Co., Jackson, Mich.

Stevens, J. B., Chevrolet Gear & Axle, Detroit, Mich.

Stevenson, S. S., U. S. Navy Dept., Portland, Oreg.

Stubbe, S. R., Allis-Chalmers Mfg. Co., Hyde Park, Mass.

Sursaw, C. A., Tennessee Eastman Corp., Oak Ridge, Tenn.

Swanson, O. J., U. S. Coal and Coke Company, Gary, W. Va.

Ward, M., The Hydro-Elec. Power Comm. of Ontario, Toronto, Ont., Canada

Wescott, R. H., Jr., Comdr., U. S. Navy, c/o F.P.O., New York, N. Y.

Whittaker, G. B., Chase Brass and Copper Co., Cleveland, Ohio

Williams, C. M., Westinghouse Elec. Corp., E. Pittsburgh, Pa.

Woodruff, F. E., Freese and Nichols, Fort Worth, Tex.

63 to grade of Member

### To Grade of Associate

**United States and Canada**

1. North Eastern

Bronerwine, C., Estate of J. M. Bronerwine, Norwich, Conn.

Chigas, V., Sylvania Elec. Prod., Inc., Boston, Mass.

Childs, J. N., Jr., Lt. (jg), USNR, Naval Research Laboratory, Boston, Mass.

Clendening, H. C., U. S. Military Academy, West Point, N. Y.

DeWolf, F. T., General Elec. Co., West Lynn, Mass.

Ellington, Ohio Brass Co., Boston, Mass.

Finnell, W. J., American Bosch Corp., Springfield, Mass.

Gallagher, E. S., General Elec. Co., Schenectady, N. Y.

Garber, D. S., American Bosch Corp., Springfield, Mass.

Hussey, E. S., Raytheon Mfg. Co., Waltham, Mass.

Kemphaus, J. V., Westinghouse Elec. Corp., Boston, Mass.

Kenyon, C. H., Corning Glass Works, Corning, N. Y.

Kraft, L. M., Southern New England Tel. Co., New Haven, Conn.

Lee, E. M., General Elec. Co., Schenectady, N. Y.

Lord, R. T., New Hampshire Gas and Elec. Co., Portsmouth, N. H.

Lowell, H. T., Jr., Westinghouse Elec. Corp., Boston, Mass.

Mac Donald, K. G., General Elec. Co., Schenectady, N. Y.

McGowan, L. F. (Re-election), N. Y. State Elec. & Gas Corp., Binghamton, N. Y.

Moore, J. K., Alden Products Co., Brockton, Mass.

Mueller, F. J., Bethlehem Steel Co., Quincy, Mass.

Roberts, W. M., U. S. Navy, Naval Air Station, Squantum, Mass.

Sandblom, W. B., Navy Yard, Boston, Mass.

Schofield, M. W. (Re-election), American Woolen Co., Lawrence, Mass.

Shea, H. B., Boston Edison Co., Boston, Mass.

Stalser, T. R., Cornell Aeronautical Lab., Buffalo, N. Y.

2. Middle Eastern

Alexander, F. L., National Carbon Co., Inc., Cleveland, Ohio

Ansley, E. V., Stackpole Carbon Co. of St. Mary's Pa., Dayton, Ohio

Ayers, D. P., Copperweld Steel Co., Glassport, Pa.

Bachelor, H. P., Westinghouse Elec. Corp., Baltimore, Md.

Birge, E. C., Virginian Elec., Inc., Charleston, W. Va.

Brightfelt, J. C., General Elec. Co., Erie, Pa.

Broemer, F. A., Westinghouse Elec. Corp., Baltimore, Md.

Brown, J. P., Lt., A. C., Air Technical Serv. Command, Wright Field, Dayton, Ohio

Cadwell, D. L., Westinghouse Elec. Corp., E. Pittsburgh, Pa.

Caplow, A. I. (Re-election), Columbia Elec. Mfg. Co., Cleveland, Ohio

Donahue, T. M., General Elec. Co., Erie, Pa.

Edmunds, R. E., Pennsylvania Power & Light Co., Hazleton, Pa.

Ewing, J. S., The Hertner Elec. Co., Cleveland, Ohio

Gandy, B. B., New York Shipbuilding Corp., Camden, N. J.

Gordy, E. M., Consolidated Gas, Elec. Lt., & Power Co., Baltimore, Md.

Hamel, R. E., Cleveland Elec. Illuminating Co., Cleveland, Ohio

Hardove, W. B., Bethlehem-Sparrows Point Shipyard, Inc., Sparrows Point, Md.

Hill, F. A., Bureau of Ordnance, Navy Dept., Washington, D. C.

Hughes, J. F., H. A. Kuljian and Co., Philadelphia, Pa.

Ketter, G. S., B. F. Goodrich Co., Akron, Ohio

La Sota, L. S., Pennsylvania Transformer Co., Heidelberg, Pa.

Lenz, H. R., Philadelphia Elec. Co., Philadelphia, Pa.

Liston, D. S., General Elec. Co., Erie, Pa.

Loeblich, F., Westinghouse Elec. Corp., Sharon, Pa.

Meyer, G. E., Allis-Chalmers Mfg. Co., Norwood, Ohio

Molina, M. J., Westinghouse Elec. Corp., East Pittsburgh, Pa.

Morgan, A. G., Kanawha Rail & Machinery Co., Charleston, W. Va.

Musick, G. N., Thomas A. Edison, Inc., Huntington, W. Va.

Pantis, H. J., Philadelphia Elec. Co., Philadelphia, Pa.

Parente, F. A., General Elec. Co., Dayton, Ohio

Pool, E. L., Lt. (jg), USNR, Naval Research Laboratory, Washington, D. C.

Robbins, P. H., Metropolitan Edison Co., Reading, Pa.

Schaul, M. H., Kanawha Rail & Machinery Co., Charleston, W. Va.

Shafer, D. B., Monongahela Power Co., Parkersburg, W. Va.

Small, W. R., Jr., Pennsylvania Water & Power Co., Holtwood, Pa.

Stone, H. B. (Re-election), Robbins & Myers, Inc., Springfield, Ohio

Taborsky, S., Glenn L. Martin Co., Baltimore, Md.

Ulrikson, K. B., The Ohio Bell Tel. Co., Dayton, Ohio

Vassar, R. L., Rural Electrification Administration, Washington, D. C.

Webb, J. B., Robbins and Myers, Inc., Springfield, Ohio

Widmann, F. W., RCA Victor Div., RCA, Camden, N. J.

Wigert, J. W., Westinghouse Elec. Corp., Cleveland, Ohio

Wrobbel, W. J., Cleveland Elec. Ill. Co., Cleveland, Ohio

3. New York City

Aronoff, M., Western Elec. Co., New York, N. Y.

Backer, L. E., Stevens Institute of Technology, Hoboken, N. J.

Bayley, W. R., Public Service Elec. & Gas Co., Irvington, N. J.

Berner, J. F., Morganite Brush Co., Inc., Long Island City, N. Y.

Borjes, A., Western Elec. Co., New York, N. Y.

Caradonna, V. (Re-election), Consolidated Edison Co., New York, N. Y.

Chusmir, J., New York Naval Shipyard, Brooklyn, N. Y.

Connors, W. M., Crocker-Wheeler, Ampere, N. J.

Corcoran, J. A., Consolidated Edison Co., New York, N. Y.

Dunaberre, H. W., Comdr., USNR (Re-election), Rocke Int'l. Corp., New York, N. Y.
Franklin, W. M., Phelps Dodge Copper Products Corp., Yonkers, N. Y.
Jarvis, D. M., Automatic Switch Co., New York, N. Y.
Kraus, R. D., Mack Mfg. Co., Plainfield, N. J.
Lasal, N., Bell Tel. Labs., New York, N. Y.
Marts, L. W., Public Serv. Elec. & Gas Co., Newark, N. J.
McShea, W. T., Jr., The Lummus Co., New York, N. Y.
Meyer, F. R., Federal Tel. & Radio Corp., Belleville, N. J.
Mochnick, P., 2239 Creston Ave., New York, N. Y.
Primm, J. F., Continental Elec. Co., Inc., Newark, N. J.
Quinn, W. T., The American Bureau of Shipping, New York, N. Y.
Reimerdes, R. O. (Re-election), Bell Tel. Labs., Inc., New York, N. Y.
Rooney, H. M., Public Service Elec. & Gas Co., Newark, N. J.
Shachmut, W., National Lead Research Lab., Brooklyn, N. Y.
Swift, J. J., Dept. of Public Works City of N. Y., N. Y.
Weinrich, J., Crocker-Wheeler Elec. Mfg. Co., Ampere, N. J.
Witham, H. W., U. S. Rubber Company, Passaic, N. J.

4. Southern

Balch, L. C., Westinghouse Elec. Corp., Knoxville, Tenn.
Bonsor, J. R., Mathieson Alkali Works, Lake Charles, La.
Bozeman, F. B., J. E. Sirrine and Co., Greenville, S. C.
Boyd, J. G., Southwestern Gas and Elec. Co., Shreveport, La.
Cogan, I., Georgia School of Technology, Atlanta, Ga.
Crawley, A. O., Bureau of Yards and Docks, Norfolk, Va.
Evans, L. L., Alabama Power Co., Birmingham, Ala.
Ford, H. G., Jr., Birmingham Elec. Co., Birmingham, Ala.
Griffith, J. A., Birmingham Elec. Co., Birmingham, Ala.
Gunn, P. L., Southwestern Gas & Elec. Co., Shreveport, La.
Lemon, H. Jr., Chesapeake & Potomac Tel. Co. of Va., Norfolk, Va.
Major, F. H. (Re-election), Tennessee Valley Authority, Chattanooga, Tenn.
McDowell, S. J., American Lava Corp., Chattanooga, Tenn.
Meriwether, G. M., 2226 Third Avenue North, Birmingham, Ala.
Monroe, E. H., Tennessee Valley Authority, Knoxville, Tenn.
Osborne, N. M., Jr., General Elec. Co., Norfolk, Va.
Polk, W. E., Polk Elec. Co., Shreveport, La.
Pons, C. M. L., Davis-Pons Elec. Co., Shreveport, La.
Sprowl, S. M., Jr., (Re-election) Duke Power Co., Greensboro, N. C.
Swearingen, C. T., Jr., 2211 Wright Ave., Greensboro, N. C.
Warren, J. D., Louisville Gas & Elec. Co., Louisville, Ky.
Wood, C. D., General Elec. Co., Richmond, Va.

5. Great Lakes

Ass, E. A., Farnsworth Tel. & Radio Corp., Ft. Wayne, Ind.
Ascher, G., Progressive Welder Co., Detroit, Mich.
Austin, L. E., North Dakota Agricultural College, Fargo, N. D.
Avery, C. C., General Foods Corp., Battle Creek, Mich.
Barbier, G. H., Electrical Inspection and Servicing Co., Detroit, Mich.
Bonnell, J. R., Consolidated Cement Corp., Cement City, Mich.
Brown, C. R., 329 N. Lee St., Iowa City, Iowa
Campbell, A. R., Westinghouse Elec. Corp., Chicago, Ill.
Carlson, W. R., Commonwealth Edison, Chicago, Ill.
Cogswell, C. G., Public Lighting Comm., Detroit, Mich.
Drummond, J. W., The Detroit Edison Co., Detroit, Mich.
Esau, W. A., Board of Education, Saginaw, Mich.
Frankenfeld, W. A., The Detroit Edison Co., Detroit, Mich.
Gallicchio, F. V., Commonwealth Edison Co., Chicago, Ill.
Glassow, F. A., Barber-Colman Co., Rockford, Ill.
Gustafson, G. A. (Re-election), Minnesota Power and Light Co., Duluth, Minn.
Hammerstrom, A. A., Minnesota Power & Light Co., Duluth, Minn.
Holland, D. B., Cutler-Hammer, Inc., Milwaukee, Wis.
Huntsinger, G. O., Delco Remy Div., General Motors, Anderson, Ind.
Keeley, E. E., Northern Indiana Public Service Co., Hammond, Ind.
Kohler, R. W., Commonwealth Edison Co., Chicago, Ill.
Krebs, J., Jr., Western Elec. Co., Inc., Cicero, Ill.
Mayfield, W. A., Vern E. Alden, Engineers, Chicago, Ill.
McCollum, T. A., Western Elec. Co., Chicago, Ill.
Miner, C. E., Vern E. Alden, Engineers, Chicago, Ill.
Oberhausen, J. J., Commonwealth Edison Co., Chicago, Ill.
Plenger, W. D., Public Service Co. of Northern Ill., Maywood, Ill.
Pogod, R., Capacitron Co., Chicago, Ill.
Popiel, W. F., Prewett Elec. Co., Peoria, Ill.
Preston, L. R., Commonwealth Edison Co., Chicago, Ill.
Sheffield, B. H., Commercial Solvents Corp., Peoria, Ill.
Smith, E. F., Vickers, Inc., Detroit, Mich.
Smith, P. E., Public Service Co. of No. Ill., Chicago, Ill.
Sorenson, H. (Re-election), Wisconsin Elec. Power Co., Milwaukee, Wis.
Stevenson, A. R., Dept. of Public Works, Detroit, Mich.
Stone, S. P., Public Lighting Comm., Detroit, Mich.
Toutenhoofd, W. L., Western Elec. Co., Detroit, Mich.
Valentine, R. E., Spaulding Fibre Co., Fort Wayne, Ind.
Walters, G. E., Caterpillar Tractor Co., East Peoria, Ill.
Wechsler, L., Bendix Aviation Corp., South Bend, Ind.
Wilson, J. P., Tri-State College, Angola, Ind.
Wright, J. W., Michigan Bell Tel. Co., Saginaw, Mich.
Zeller, G. A., Int'l. Business Mach. Corp., Peoria, Ill.

6. North Central

Halle, S. (Re-election), Halle Electric Co., Colorado Springs, Colo.
Post, L. A., Public Service Co. of Colorado, Denver, Colo.
Scussel, F. G., Public Service Co. of Colorado, Denver, Colo.

7. South West

Beale, W. E., Baker Engg., San Antonio, Tex.
Bourne, R. D., University of Texas, Austin, Tex.
Bowen, R. L., Community Public Service Co., Ft. Tex.
Cook, B. J., Oklahoma Gas and Elec. Co., Oklahoma City, Okla.
Covington, J. K., Freese and Nichols, Fort Worth, Tex.
Feather, A. M., Community Public Service Co., Fort Worth, Tex.
Glasco, C. E., Kansas Gas & Elec. Co., Wichita, Kan.
Hall, H. H., Kansas City Power & Light Co., Kansas City, Mo.
Hart, W. G., Public Service Co., Tulsa, Okla.
Hildebrand, W. F., General Elec. Co., Tulsa, Okla.
Hixon, J. L., General Elec. Co., Houston, Tex.
Kayser, C. S., Houston Lighting & Power, Houston, Tex.
Lee, F. N., Humble Pipe Line Co., Houston, Tex.
Liggett, W. E., Southwestern Bell Tel. Co., St. Louis, Mo.
Moll, D. E., 609 East Fifth St., Hutchinson, Kan.
Pool, J. L., Magnolia Pipe Line Co., Dallas, Tex.
Shearer, W. E., Shearer Elec. Co., Little Rock, Ark.
Sherwood, R. W., Gulf States Utilities Co., Beaumont, Tex.
Woodman, C. M. (Re-election), Southwestern Bell Tel. Co., Dallas, Tex.

8. Pacific

Airgood, W. H., General Elec. Co., Oakland, Calif.
Best, N. L., John Manville Sales Corp., San Francisco, Calif.
Bowen, D. L., North American Aviation, Inglewood, Calif.
Brown, R. N., Lt., USNR, San Francisco Naval Shipyard, San Francisco, Calif.
Christie, A. B., Southern Calif. Edison Co., Ltd., Los Angeles, Calif.
Farmer, F. H., Tide Water Associated Oil Co., Associated, Calif.
Fink, R. C., Dept. of Water & Power, Los Angeles, Calif.
Fulton, F. C., Imperial Irrigation Dist., Imperial, Calif.
Grimes, G. R., Southern California Edison Co., Los Angeles, Calif.
Kirkpatrick, A. B. (Re-election), 252A Mosley Ave., Alameda, Calif.
McCann, J. J., Pacific Gas & Elec. Co., San Francisco, Calif.
McCormick, J. G., General Elec. Co., San Francisco, Calif.
Meyer, J. H., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Michelini, L. E., San Francisco Naval Shipyard, San Francisco, Calif.
Parr, C. W., Western Elec. Co., Los Angeles, Calif.
Partridge, R. W., Lockheed Aircraft Corp., Burbank, Calif.
Schermerhorn, G. D., Public Works Dept., U. S. Navy, San Diego, Calif.
Schricker, G. R., North American Aviation, Inc., Inglewood, Calif.
Short, H. A., Colorado River Agency, Parker, Ariz.
Thielman, N. W., Lockheed Aircraft, Burbank, Calif.
Turpen, R. D., General Elec. Co., Los Angeles, Calif.
Van Marter, C. R., Union Oil Co., Oleum, Calif.
Weaver, V. L., General Elec. Co., Los Angeles, Calif.
White, C. C., U. S. Naval Air Station, North Island, San Diego, Calif.
Yarnell, N. R., Southern Calif. Edison Co., Los Angeles, Calif.

9. North West

Ango, F. S. (Miss), Bonneville Power Admn., Portland, Oreg.
Belsher, M. W., Bonneville Power Admn., Portland, Oreg.
Berg, N. J., Puget Sound Naval Shipyard, Portland, Oreg.
Boston, J. R., Bonneville Power Admn., Portland, Oreg.
Brewster, R. W., Bonneville Power Admn., Portland, Oreg.
Brintzenhoff, T. O., Portland Housing Authority, Vanport City, Oreg.
Burns, G. L., Bonneville Power Admn., Portland, Oreg.
Collins, H. E., Westinghouse Elec. Corp., Portland, Oreg.
Cramer, W. W., The Pacific Tel. & Tel. Co., Portland, Oreg.
Ekroth, W. W., Bonneville Power Admn., Portland, Oreg.
Fleming, A. E., General Elec. Supply Corp., Salt Lake City, Utah.
Garland, W. R., Boeing Aircraft Co., Seattle, Wash.
Hillend, V. J., Commercial Iron Works, Portland, Oreg.
Hughart, C. R., Bonneville Power Admn., Portland, Oreg.
Johnson, D. A. (Re-election), Bonneville Power Admn., Portland, Oreg.
King, J. K., Administration Building, Vanport City, Portland, Oreg.
Kittner, F. J., Bonneville Power Admn., Portland, Oreg.
McLean, J. J., Bonneville Power Admn., Vancouver, Wash.
Miller, H. N., Westinghouse Elec. Corp., Portland, Oreg.
Moiseeff, A. S., Lieut. (jg), U.S.N., A. I. M., Portland, Oreg.
O'Brien, L. E., Bonneville Power Admn., Portland, Oreg.
Pashley, H. B., Bonneville Power Admn., Portland, Oreg.
Scheuerman, L. N., Bonneville Power Admn., Vancouver, Wash.
Schroeder, H. B., Bonneville Power Admn., Portland, Oreg.
Smith, G. A. A., Elec. Smith Co. Contractors, Spokane, Wash.
Thornburg, D. H., General Elec. Co., Seattle, Wash.
Wall, C. E., U. S. Engineers, Portland, Oreg.
Weber, J. G., 1231 S. E. 58th Ave., Portland, Oreg.
Weiner, L., Bonneville Power Admn., Portland, Oreg.
Willis, R. C., Northwestern Elec. Co., Vancouver, Wash.
Woster, R. E., Northwestern Elec. Co., Vancouver, Wash.

10. Canada

Blakeley, W. R., The Hydro-Elec. Power Comm. o Ontario, Toronto, Ont., Canada
Carter, R. B., Canadian Westinghouse Co., Hamilton, Ont., Canada
Haines, J. L., Canadian Westinghouse Elec. Corp., Hamilton, Ont., Canada
Smith, H. A., Hydro-Elec. Power Comm. of Ontario, Toronto, Ont., Canada

Elsewhere

Bebbington, D. W. G., Dominion Physical Lab., Wellington, N. Z.
Bernal, R., Jr., F. R. Transportation Authority, Hato Rey, P. R.
Bhatt, N. N., Bombay Gaurage (Rajkot), Ltd., Rajkot, Kathiawar, India
Bowman, W. G., Westmorland & Dist. Elect. Supply Co., Ltd., Westmorland, England
Camarena M., P., Donceles 106, Desp. 24, Mexico City, Mex.
Carbajal S., A., Cia Distribuidora Westinghouse, S. A., Mexico City, Mex.
Celada S., J., Nacional de Electricidas S. A., Torreon, Coah., Mex.
Garcia, J. B., Cia. Nacional de Electridad S. A., Torreon, Coah., Mex.
Kenney, B. D., Tropical Oil Company, Bogota, Columbia, S. A.
Kiolios, L. M., American Farm School, Salonika, Greece
Lliteras, J. A., P. O. Box 425, Ponce, P. R.
Machado Z. O., Electricidad de Caracas, Caracas, Venezuela, S. A.
Marshall-Wood, J., Admiralty Signal Est., Manchester, England
Neckelmann E., R. H., Wessel, Duval & Co., S. A. C., Santiago de Chile, S. A.
Patel, J. L., Kaar Sugar Works, Ltd., Baheri U. P., India
Rajgarhia, C., India Mica Supplies Co., Ltd., Ghiridi, India
Riemann D., R., Comision Federal de Elect., Mexico D. F., Mex.
Robertson, A., Messrs. Bruce Peebles, Co., Ltd., East Pilton, Edinburgh, Scotland
Singh, H., P. W. D., Punjab, Lahore, India
Tikare, T. B., British Insulated Callender's Cables, Ltd., Bombay, India

Total to grade of Associate
United States and Canada, 241
Elsewhere, 20

# OF CURRENT INTEREST

## Great Barrington Celebrates First A-C Street Lighting

The first community in America to be lighted by a-c electricity, Great Barrington, Mass., observed the 60th anniversary of the event March 23, 1946, when Governor Maurice J. Tobin unveiled a plaque memorializing the achievement of William Stanley and George Westinghouse.

The bronze plaque, which will be mounted on a granite stone on the lawn in front of the Town Hall, is inscribed:

Commemorating the life and work of George Westinghouse and William Stanley, ingenious inventors and pioneer organizers of the electrical industry.

Who made possible America's first town lighting system by the use of alternating electric current at Great Barrington, Massachusetts, March 20, 1886.

Erected on the sixtieth anniversary of the occasion and in the one hundredth anniversary year of the birth of George Westinghouse, by the Westinghouse Electric Corporation. Unveiled by Governor Maurice J. Tobin of the Commonwealth of Massachusetts March 23, 1946.

Presentation was made by Frank L. Nason (A '43) manager of the New England district for the Westinghouse Electric Corporation. It was accepted for the town by Francis J. Kelly, president of the Board of Selectmen. Judge Thomas F. Conneally of the Southern Berkshire District Court presided during the ceremonies.

William Stanley, who was thus honored, became associated with the Westinghouse organization in 1884 and installed and equipped an incandescent lamp factory at Swissvale, Pa. When, in 1885, at the age of 27, he moved because of illness from Pittsburgh, Pa., to Great Barrington, he set up the first a-c plant in America, incorporating his ideas on long-distance light and power transmission, and in 1886 this plant distributed to the town 500 volts through transformers connected in multiple. The Westinghouse company then took over the manufacturing details and installed the Stanley apparatus at Niagara Falls, N. Y.

## Communications Center at UN Headquarters

A complete domestic and international telegraph, telephone, cable, and radio communications center was established at Hunter College, New York, N. Y., for the use of the United Nations during the current Security Council meetings. High speed radiotelegraph and cable service to all parts of the world thus is available to the press and to diplomatic representatives attending the conference.

Communications facilities for the press were set up in the college gymnasium, while on the main floor of the building a commercial office was equipped to handle diplomatic, commercial, and personal traffic for the delegates. It is estimated that during the time the conference will be in session press and government messages totaling over 1,000,000 words will be dispatched to every civilized country in the world. In addition to other facilities, television was installed to give animated contact with sessions to the bulk of the reporters and other visitors not accommodated among the limited attendants in the session hall.

## Engineering Society Presidents Laud Addition to McMahon Bill

Inclusion of a division of engineering in the commission of civilians which will administrate the use of atomic energy under terms of the McMahon Bill (S 1717), recently approved unanimously by the Atomic Energy Committee of the United States Senate, was lauded by AIEE president William E. Wickenden (F '39), together with the presidents of three other national engineering societies, in a telegram to Senator Brien McMahon of Connecticut, chairman of the committee. The message applied to the draft of the bill in committee on April 12, 1946.

The telegram, which was signed by Mr. Wickenden, W. W. Horner, president, American Society of Civil Engineers, D. Robert Yarnall, president, American Society of Mechanical Engineers, and James G. Vail, president, American Institute of Chemical Engineers, reads as follows:

"The undersigned address you as individuals who believe that the greatest possible advantage should accrue to the public welfare from the use of nuclear energy. Our profession has already contributed largely to the development of nuclear energy, several thousand engineers having been associated in engineering responsibilities in the work of the Manhattan District. We know of the destructive use of nuclear energy but our interest is in its greater use for public good.

"We agree in general with the provisions of your Senate Bill 1717 as heretofore published. We believe that the Federal administration of all matters dealing with materials fissionable by chain reaction should be in the hands of agencies that are essentially civilian in makeup. We believe that the Federal government has a responsibility for the safe use of these materials. We believe that the greatest advantage from the use of these materials will be for civilian industrial purposes. In the interest of these greater uses of nuclear energy we believe that the widest opportunity should be given for industrial research under Commission license. All use of nuclear energy for industrial purposes should be under license by the Atomic Commission but with the facilities owned by industry.

"In a forward-looking program of the extent required to develop nuclear energy for industrial purposes, it is important that sound judgment in the use of time, money, and material should be applied to the work of the Atomic Commission. Engineers in performing their daily tasks are concerned with economy in the uses of time, money, and material. As reported in recently published amendments to your Bill the inclusion of a division of engineering in the Commission meets this need. We appreciate its addition and are confident that the division will prove its worth and your wisdom in including it.

"We appreciate the tremendous responsibility you have undertaken in stating a policy for this Nation to follow in dealing with this new source of useful energy."

## NAM Opposes Kilgore-Magnuson Bill

Specifically attacking the overgreat power it lodges in the President as a potential source of undue political influence, the broad legislating it does regarding patents, its possible interference with academic freedom, and the modicum of authority with which it invests the advisory board of scientists, the National Association of Manufacturers recently expressed disapproval of the National Science Foundation bill, S 1850, through R. J. Dearborn, chairman of NAM's committee on patents and research.

Research would be hindered seriously through unwarranted Government competition if the bill were enacted, Mr. Dearborn declared. The centralization of enormous power over both science and technology in the executive department of the Government would have a disastrous effect on the free enterprise system, he stated.

NAM favors the creation of a National Science Foundation to procure the full development of this country's scientific and technical resources along the lines recommended by Doctor Vannevar Bush (F '24) director of the Office of Scientific Research and Development, in his report, "Science, the Endless Frontier," according to Mr. Dearborn.

"Instead of providing a relatively simple organization consisting of a group of people well versed in the various scientific fields who would be in a position to advise the President and make recommendations to the Congress of what they needed and how the funds to support basic science might be expended, the Kilgore-Magnuson legislation has the tendency to provide an elaborate Governmental setup," he said. This of itself would give many opportunities for the operation of the spoils system, he added.

Though the bill tries to guard against political influence by setting up an advisory board, NAM points out that there is little guarantee that this Board itself would be politically inviolable, because of powers the bill confers upon the President.

Another objection to the Board voiced by NAM is that it is only advisory and, having no authority, is unlikely to attract the best scientific brains of the country. Were it to have full responsibility for the activities of the Foundation, outstanding scientific leaders would serve on it, NAM believes.

There is also the fear by educational institutions that they will be dominated by the Federal Government, Mr. Dearborn pointed out. They feel that in other spheres of activity the use of Government funds has carried with it certain stipulations as to the methods of operation and, to some extent, even partial control.

NAM believes that legislation regarding patents does not belong in a bill for the crea-

tion of a National Science Foundation. Such legislation, it declares, should be referred to the Congressional Committee on Patents. S 1850, on the other hand, attempts to legislate with respect to all patents resulting from research and development conducted directly by the Government as well as research and development by outside agencies financed in whole or in part by the Government.

"The broadest possible power is placed in the Foundation with respect to patents," said Mr. Dearborn. "It is provided that the Administrator, in carrying out his functions, is authorized 'to acquire by purchase or otherwise, hold and dispose of by sale, lease, loan, or otherwise, real and personal property of all kinds necessary for, or resulting from, scientific research or development.' The United States Supreme Court has uniformly and repeatedly held that patents are property, and, hence, property of all kinds' certainly would include patents. NAM feels that the bill should state that this section does not authorize the Administrator to acquire patent rights by condemnation proceedings."

**Telephones in Ecuador.** Automatic telephone systems will be installed in Quito and Guayaquil, Ecuador, in accordance with a recent contract with a Swedish company. Each city will have an initial installation of 90,000 lines with a capacity for substantial increases in this number. Approximately two years will be required for the installation of the 6,000 automatic telephones that are planned for each city.

## Telephone Privacy Upheld by Bell System and USITA

Briefs upholding the "right of privacy" in telephone service against the use of recording devices in connection with telephones have been filed with the Federal Communications Commission by the Bell System telephone companies and the United States Independent Telephone Association. The briefs also opposed the prescription of a tariff regulation governing use of recording devices in interstate and foreign toll telephone service unless it secured full co-operation of the state commissions.

The Bell System brief declared that the right of privacy in telephone communications would "be infringed by use of telephone recorders without adequate notice to both parties" that the conversation was being recorded. It substantiated this by the opinion of Justice Brandeis in the case of Olmstead versus the United States stating that "the evil incident to invasion of the privacy of the telephone is far greater than that involved in tampering with the mails."

Both briefs concurred in the view that there is no record of a widespread demand for "unrestricted" use of recording devices on telephone conversations and that mechanical devices have not been found suitable to indicate to the users that a recording device is being employed. According to the Bell System brief the "operator announcement" plan is the only "practical" way to meet this requirement. However, the USITA pointed out that this plan would add expense for operation equipment and increase the work load of operators, or require more operators, and concluded that there is at this time "no positive and practical method" to notify subscribers of the presence of recording equipment.

## Hydroelectric Developments Reported in Various Countries

With the development of the Paulo Affonso Falls of the Sao Francisco River, Brazil, along the lines of the Tennessee Valley Authority, a potential hydroelectric energy estimated at 608,000 horsepower or 448,000 kw will be made available to northeastern industry of Brazil and water and power will be provided for the irrigation of lands which otherwise would be useless. As a result this region, which now is dependent upon southern Brazilian states for agricultural and manufactured products, will be able to supply many of its own needs as well as those of other parts of the country.

In Eire two dams and two power stations will be constructed on the River Erne between Belleek and Ballyshannon. The power stations will be located near Cliffhouse and Cathaleen's Falls and at first will produce an anticipated annual output of 200,000,000 kilowatt-hours which, with full development, will rise to 250,000,000 kilowatt-hours. It is estimated that three years and 1,000 workers will be required to complete the project.

Portugal currently has a total of 110 hydroelectric power plants, operating on 11 rivers, with a total capacity of 99,009 kw generating 204,971,101 kilowatt-hours of electricity. If present plans for dam and plant construction materialize, current in Portugal will be entirely hydroelectric, and output is expected to increase from the 470,000,000 kilowatt-hours used now to 1,500,000,000 kilowatt-hours in 1952. Consumption of electricity in 1943 totalled 397,452,345 kilowatt-hours of which 253,366,758 kilowatt-hours were consumed by Portuguese industry. Annual household consumption in Portugal is low; about 60 kilowatt-hours per capita as compared with 150 in Spain, 300 to 500 in Switzerland, 1,000 in Norway, and 1,225 in the United States.

Plans for the construction of an underground hydroelectric station on Lake Sevan, Armenia, and of 973 smaller hydroelectric stations throughout Russia recently were reported in the Soviet press.

The Lake Sevan project will entail construction of a 5½-kilometer tunnel through which the water from the lake will be directed. The high altitude and shape of the lake bottom at present cause evaporation of up to 97 per cent of its water. In addition to providing irrigation to a large farming area, the development is expected to influence the growth of chemical, rubber, aluminum, and food industries in Armenia.

The proposed increase in the number of hydroelectric stations is a notable one when it is remembered that the total number of such stations was 800 at the beginning of 1945. Also reported under construction were 276 small steam power stations. This activity is said to be particularly widespread in the Urals. Of the 103 units being set up in October 1945 by collective farmers in the Molotov region, 43 were already in service. In the Sverdlovsk region of the Urals 179 small hydroelectric stations were under construction in the fall of 1945, as a step toward the goal of the farmers of the region to bring electricity to 1,000 villages in 1945. Electrification of the remaining rural localities in the region has been planned for 1946.

Specifications for a hydroelectric project at Aswan, Egypt, which will require three years for completion and which will develop 500,000 horsepower have been prepared in London, the Egyptian press reports. A unique feature of the project is that the removal of the surface earth or underlying granite in the vicinity of the dam must be done by mechanical means rather than by dynamiting, to avoid the danger of weakening the twice-heightened dam.

An agreement has been reached for the preparation of plans for hydraulic works in the mountains near Athens, Greece. Preliminary studies and scientific research have been made toward the creation of artificial lakes to furnish 1,830,000,000 cubic meters to the Athens water supply. This is expected to provide electric energy from water power amounting to about 687,000,000 kilowatt-hours a year.

## Bibliography of Scientific and Industrial Reports Issued

A "Bibliography of Scientific and Industrial Reports Distributed by the Office of the Publication Board" now is being sold in weekly installments by the Superintendent of Documents, Government Printing Office, Washington, D. C.

Each issue contains a systematic catalogue of the thousands of scientific and industrial reports that are being made available to the public through the Office of the Publication Board, Department of Commerce. The bibliographies list the serial numbers, prices, and titles of newly available reports, grouped according to subject matter. A brief summary of the contents of each report is included. The reports described provide information on scientific and technical developments, processes, products, inventions, and related matters previously subject to security restrictions. The industrial reports being made by Army, Navy, and industrial experts on German and Japanese industry are included.

Prices of the weekly bibliographies vary in accordance with their size. A definite yearly subscription rate therefore cannot yet be determined. However, the Superintendent of Documents will accept an initial payment of $10 for the service and will notify subscribers when additional re-

mittance is required. Copies also may be purchased singly. The price per copy of those already issued has ranged from 15 cents up. Each issue since January 25 has covered 300 or more reports.

## Railway Electrification Planned in Europe and South Africa

Announcement of the conversion of all or part of their railroad systems to electric operation recently has been made in Belgium, Holland, Norway, France, and South Africa, according to the press in those countries.

All Norwegian main railway lines will be electrified within 15 years, Kristian Locken, the Director General of Norway's state operated railways, has announced. The Sorland line and Kongsvinger line will be completed first and the Oslo–Bergen line last. Parliamentary approval already has been given to the electrification program.

The decision to convert the whole steam-operated railway system of Holland to electric traction was made by the Netherlands Government in June 1945. Of the 373 miles electrified before the war, the overhead wires on only 75 route miles remain intact. Overhead wires have been removed from 205 miles of road and 93 miles have been stripped completely. From 46 of the 75 substations all transformers, mercury-arc rectifiers, and switchgear have been removed.

Large-scale electrification in the near future is planned by the Belgian Government, although the country now has only 27 miles of electric traction on the line between Brussels and Antwerp.

Conversion to electric traction of 206 miles of track is contemplated for the South African Railways. When the works in progress or authorized are completed, the electrified mileage in the Union of South Africa will be 847 miles.

In France electrification of the remainder of the Paris–Lyons route of the French Government Railways has been projected. The route is now 25 per cent converted from steam.

## Oak Ridge Realized Exceptional Safety Record

Management of the town of Oak Ridge, Tenn., which grew during the completion of the atomic bomb project from an initial population of 500 to one of 75,000, was accomplished by the Turner Construction Company with resulting accident frequency and severity rates lower than the national average. The company, which worked through its wholly owned subsidiary, the Roane-Anderson Company, was responsible for safety measures in both the residential and production areas of the community, as well as for providing every community need of an American city of like size.

Though excess speed normally is the enemy of safety, at Oak Ridge both speed and safety had priorities, with secrecy an ever-present condition for all operations. None of the 12,000 employees of the company knew what was being made in the production areas. Even Raymond T. Bartnett, chief safety engineer, was ignorant of what was being manufactured.

Utilities, building maintenance, and railroads were assigned to one safety engineer; dormitories, housing and cafeterias to another; medical, cleaning, construction, fuel distribution and refuse to another; salvage yards, administrative, fire department, roads and streets and farm departments to another; supplies, warehouses, coal storage, central warehousing, equipment repair and motor pool departments to another. A fleet engineer was responsible for a vehicle safety program.

Expenditures of the safety department, however, were less than one half of one per cent of the total company payroll. The entire departmental program was carried on with a total of eight safety engineers, one fleet engineer with a driver training assistant, one statistical engineer, one statistical assistant, and five clerical assistants. With its major responsibility an industrial safety program, the department dealt with every conceivable type of working exposure.

"While we had our share of the more interesting and dramatic problems, such as fumigation with hydrocyanic acid gas and methyl bromide, railway freight operations of labeled cargoes, high voltage operations and maintenance, operation of an abbatoir and others, we still had the usual floor falls and material handling troubles," according to Mr. Bartnett.

In spite of all abnormal circumstances, the above-average safety record was established. The national frequency average computed and weighed for similar operations was 20.27. The Roane-Anderson 1944 cumulative frequency was less than

## Tower for Microwave Experiments

**Construction of a 300-foot tower to be used as an experimental laboratory and center for microwave radio functions was begun recently at Nutley, N. J., by the Federal Telephone and Radio Corporation of Newark, N. J. The "microwave tower" will be used for experiments such as frequency modulated broadcasting, televison, pulse time modulated broadcasting, aerial navigation, and radar applications which previously had to be made in tall office buildings or other tall structures not well adapted to the purpose. Special antenna mounts have been devised to simplify the installation and removal of antennas for experimental work and the upper decks and roof of the tower will be heated to preclude the formation of snow and ice. In addition to the tower, a two story laboratory also is being erected. This building will be of dry-wall construction, aluminum on the outside with glass wool insulation and partitions of asbestos compound on the interior**

50 per cent of this, and for the first eight months of 1945 was less than 30 per cent of the national average. Severity rates were under 40 per cent of the national average.

## Microwave Bands Standardized By National Bureau

The entire microwave range up to 33,000 megacycles per second has been arranged, in the radio frequency standards recently established by the National Bureau of Standards of the Department of Commerce, to give some degree of order to the rapid wartime developments expected to revolutionize radiobroadcasting. The term microwave has been applied to frequencies above 1,000 megacycles per second, and the new range is about 30,000 times higher than the present broadcast band.

For purposes of classification and allocation, microwaves are divided into four bands, with the following nomenclatures:

| Designation | Symbol | Megacycles | Wavelength in Centimeters |
|---|---|---|---|
| High | HF | 3– 30 | 10,000–1,000 |
| Very high | VHF | 30– 300 | 1,000– 100 |
| Ultrahigh | UHF | 300– 3,000 | 100– 10 |
| Superhigh | SHF | 3,000–30,000 | 10– 1 |

The new standards have an accuracy of one part in 10 million. In the ultrahigh and superhigh frequency bands, this accuracy is better than one part in 100 million. These fixed frequencies cover the two bands at intervals of approximately one per cent, which is the normal separation between stations operating in the conventional broadcast band.

The number of new channels and the high degree of precision in the separation makes available the largest possible number of usable channels and reduces interference to a minimum. Generally speaking, microwaves extend from 10 centimeters down, and the Bureau of Standards experts now are working on the millimeter region.

## FCC Institute Survey of Overseas Communications

With a view toward the formulation of a policy for the future development of radiotelegraph service from the United States to foreign points, the Federal Communications Commission has planned a general review of the present status of overseas communications. All international radiotelegraph carriers were invited by the FCC to file renewal applications of licenses expiring December 1, 1946, for point-to-point stations in the fixed public service. The applications set forth all points the carriers propose to serve during the new license period including those for which they are authorized on a special temporary basis.

Recent disclosures by the War Department reveal that its radioteletype channel between Washington, D. C., and Moscow will be taken over by RCA Communications and Mackay Radio some time in May. A similar arrangement has been made with regard to the British channels which were joint government operated before the war. In response to reports that the Washington–Moscow channel had its terminus in the Pentagon building, the War Department pointed out that the circuit actually is connected to the Soviet Embassy and that only switching and relaying equipment is located in the Pentagon.

## Supersonics Find Military and Industrial Applications

The term supersonic has been applied to any kind of vibration above 20,000 cycles per second—the highest frequency the human ear can detect. An invaluable agent during the war the peacetime applications of supersonics are increasing daily.

Flaws inside metals of any thickness can be detected through its use. The sound waves can be sent through metal in a manner which permits plotting of the approximate size, shape, and location of flaws. Others of the varied applications include acceleration of chemical reactions, alloying metals, in television reception, for photographic emulsions, and for clearing smoke out of the air through the process of precipitation.

Supersonics, which travel 4,200 feet per second through water, helped during the war to combat Axis submarines by making it possible to detect the range of the underwater craft.

**Mexican Communications.** Mexico's telecommunications system will be modernized to connect Mexico with the entire world according to a recent announcement of the Mexican Ministry of Communications and Public Works. Modernization of the radiotelephonic and radiotelegraphic services, authorized by President Camacho, will be carried on this year, and for this purpose equipment valued at five million Mexican pesos (about $1,000,000) has been acquired from American manufacturers.

**Army Purchase Information.** A Purchase Information Section has been established under the Procurement Division, United States Army Service Forces, Room 3 C 467, The Pentagon, Washington, D. C., to display to prospective bidders and interested persons invitation for an abstracts of bids issued by Army contracting officers for Army equipment, supplies, and construction. Under a recently established policy of the War Department procurement shall be by formal advertising and competitive bidding whenever practicable and, though authority to negotiate contracts still exists, it is to be exercised only in cases where advertising procedures are likely to produce less favorable results.

**Argentine Engineers Honor American.** Dean S. S. Steinberg of the University of Maryland college of engineering has been notified of his election as an honorary member of the Argentine Society of Engineers, Buenos Aires, Argentina, "in recognition of his professional attainments and his outstanding work in promoting closer relations among the members of the engineering profession in the three Americas." During his good-will tour of Latin America last summer, under the auspices of the United States Department of State and as the representative of engineering societies in the United States, he was similarly honored in Ecuador, Uruguay, and Mexico.

**Registration of Engineers.** An injunction has been granted the Ohio Society of Professional Engineers by the Common Pleas Court to enjoin Designers for Industry, Inc., Cleveland, perpetually from causing or authorizing any officer, director, agent, or employee who is not a registered professional engineer under the laws of Ohio to practice or offer to practice engineering in Ohio. This is the first suit filed by the society and amounts to holding valid the engineers registration act of Ohio, sustaining a society contention that injunction suits may be brought against nonregistered persons who attempt to practice engineering.

# RESEARCH • • • •

## Grants for Research Made; Engineering Work in Minority

An initial list of Frederick Gardner Cottrell special grants in aid of postwar research totaling nearly $175,000 has been announced by Joseph W. Barker (F '30) president of the Research Corporation, New York, N. Y.

Additional grants will be forthcoming upon recommendation of the corporation's advisory committee which at present has other applications under investigation. The corporation is interested in receiving high quality applications for grants from engineering and smaller liberal arts colleges. In the list just issued, engineering research problems are most notable for their scarcity. Research Corporation explains this by saying that engineering schools simply have not submitted supportable projects so far, though hope is expressed that they soon will.

According to Doctor Barker, initial grants are not made for more than one year at any one time, except in rare cases, although support will be continued for four or five years if progress of the project warrants it.

A special fund of $2,500,000 was established in 1945 to inaugurate the Cottrell grants-in-aid, because it is believed that the immediate postwar period is a crucial one for research and teaching in American edu-

cational institutions, Doctor Barker explained.

With the pattern of research in colleges and universities disrupted by the war educators face the problem of whether talented men drafted into war research "can be brought back to the college laboratories and classrooms where there is great necessity for them, if we are to re-establish adequate research closely associated with inspired teaching," Doctor Barker said. He pointed out that the strain imposed upon teaching staffs by the flood of returned veterans may hinder the re-establishment of adequate fundamental research.

"It was felt that such a program of aid to fundamental research in the pure and applied sciences would be of great value at this time when wartime research men are considering whether to return to educational institutions or to accept industrial positions.

Following is a list of the institutions, the projects, and their directors to which the initial Frederick Gardner Cottrell special grants-in-aid for postwar research have been made:

AMHERST COLLEGE, for design and construction of equipment for measuring faint stars by the photoelectric method; Doctor John S. Hall.

BOSTON UNIVERSITY, for an experimental examination of the properties of the solvated electron by calorimetric, density, and viscosity studies of the alkali metal liquid ammonia systems; Professor Lowell V. Coulter.

UNIVERSITY OF CALIFORNIA, for the correlation of photochemical processes with molecular absorption spectra; Doctor F. E. Blacet.

CARNEGIE INSTITUTE OF TECHNOLOGY, for work on the properties of matter at extremely low temperatures. Superconductivity, especially of thin films; Professor Immanuel Estermann.

CATHOLIC UNIVERSITY, for a study of chemical reactions between gases and solids; Doctor Walter John Moore, Jr.

DUKE UNIVERSITY, for a study of microwave absorption spectra of molecules; Doctor Walter Gordy.

INDIANA UNIVERSITY, for a study of beta disintegration process; Doctor L. M. Langer.

KANSAS STATE COLLEGE, for a study of photoelectric and thermionic properties of spectroscopically and thoroughly outgassed nickel with emphasis on studies at the Curie point; Doctor A. B. Cardwell.

MICHIGAN STATE COLLEGE, for a study of ionization produced in gases by electrons of energies less than 2,000 electron volts; Doctor Thomas H. Osgood.

UNIVERSITY OF MINNESOTA, for an analysis of electron and ion collision phenomena in gases and vapor; Doctor John T. Tate.

UNIVERSITY OF MINNESOTA, for research on isotopes; Doctor A. O. C. Nier.

MUHLENBERG COLLEGE, for the measurement of the velocities and absorption coefficients of sound waves in gases as a function of temperature and pressure at various supersonic frequencies; Doctor I. F. Zartman.

UNIVERSITY OF NEW HAMPSHIRE, for a study of inorganic fluorides; Doctor H. M. Haendler.

NORTH TEXAS STATE TEACHERS COLLEGE, for stereoisomerism of synthetic and natural polyenes; Doctor R. B. Escue, Jr.

NEW YORK UNIVERSITY, Investigation of nuclear disintegrations produced by cosmic radiation; Doctor Serge A. Korff.

UNIVERSITY OF NOTRE DAME, for the extension of experiments on the excitation of nucleuses by X rays and electrons by observation of shorter metastable lifetimes and for the extension of experiments on the excitation of nucleuses by X rays and electrons by increasing excitation energy; Doctor George B. Collins, Doctor Bernard Waldman.

OHIO STATE UNIVERSITY, for work on infrared spectra of a large number of polyatomic molecules measured automatically under high dispersion; Doctor H. H. Nielsen.

OREGON STATE COLLEGE, for synthesis of amino alcohols derived from pyrimidines and quinazolines; Professor B. E. Christensen.

PENNSYLVANIA STATE COLLEGE, for study of influence of range of stress on the fatigue strength of metals subjected to axial and biaxial stresses; Doctor John A. Sauer.

UNIVERSITY OF PENNSYLVANIA, for work in nuclear physics; Doctor G. P. Harnwell.

QUEENS COLLEGE, for isotope research; Doctor M. L. Eidinoff.

RUTGERS UNIVERSITY, for work on nuclear and electronic paramagnetism at room and low temperatures; Doctor F. G. Dunnington.

STANFORD UNIVERSITY, for research on nuclear induction and its application to polarized neutrons; Doctor Felix Bloch.

STEVENS INSTITUTE OF TECHNOLOGY, for a study of absorption spectra, particularly in the far ultraviolet, of liquids to be followed later by studies of other properties, etc. Doctor E. G. Schnieder.

TUSKEGEE INSTITUTE, for research on the methods of preparation and the chemical properties of the bisbromhated ethers; Doctor C. T. Mason.

SOUTHWESTERN AT MEMPHIS, for a study of vapor phase catalytic preparation of high molecular weight ketones; Doctor J. L. A. Webb.

UNIVERSITY OF TULSA, for a study of distribution of carbon dioxide in systems containing two liquid phases; Doctor F. T. Gardner.

STATE COLLEGE OF WASHINGTON, for study of (*a*) Enthalpy changes at unit surfaces on wetting of solids by liquids; (*b*) a study of significance of variations in the values of the densities of fine powders as measured in various liquid media; (*c*) development of new techniques for the study of liquid films at solid-liquid interfaces; Professor J. L. Culbertson.

UNIVERSITY OF WYOMING, for research on determination of neutron resonance energies and half life periods of induced radio activities; Doctor Emil J. Hellund.

Research Corporation is a nonprofit organization devoted to advancing research and technology by use of revenues from patents assigned to it by interested inventers. The corporation was established in 1912 with the gift, through Doctor Frederick Gardner Cottrell, of patent rights on electrical precipitation. The corporation since has served colleges and universities by the administration of patents arising from researches in their laboratories. From the proceeds it has aided some 52 institutions by grants totaling more than $1,250,000.

The following is the advisory committee which examines the worth of applications for the grants:

Doctor W. D. Coolidge (M '34) of the General Electric Company laboratories, Doctor Thomas N. Chilton of the Du Pont company, Doctor Lloyd P. Smith of Cornell University, Mr. Timothy E. Shea of Western Electric Company, Colonel Staffer Warren of the Medical School of the University of Rochester, and Doctors R. R. William and J. W. Barker of Research Corporation.

**Purdue Studies Electrified Farm.** The study of "the proper and more efficient use of electric power in rural areas" has been undertaken at Purdue University, Lafayette Ind. Plans for the project call for the purchase of a general purpose farm where studies can be made of at least 200 applications of electricity to farm chores.

## Mobile Capacitor Unit for Power Lines

**This 4150-volt capacitor unit designed by the General Electric Company will help carry emergency and seasonal overloads for the Consolidated Gas, Electric Light, and Power Company of Baltimore, Md. It consists of six 180-kilovar banks of Pyranol capacitors mounted on a Fruehof model 5 semitrailer chassis. Three of the banks are arranged for automatic control and three for manual. The capacitor equipment is connected to the lines by means of cables carried on reels in a rear compartment. A Magne-blast circuit breaker protects the unit**

## Navy Reveals Secret Gas Turbine to Editors

At the Naval Engineering Experiment Station, Annapolis, Md., the Navy lifted its wartime veil of secrecy March 29, 1946, and demonstrated its experimental gas turbine to a group of technical editors of national publications. Built by the Allis-Chalmers Manufacturing Company, this experimental gas turbine has been under test at Annapolis for the past two years.

The turbine has been operating at 1,350 degrees Fahrenheit, the highest temperature yet sustained for long periods of time for such a machine, and it is hoped gradually to raise the operating temperature to 1,500 degrees Fahrenheit. The instrumentation of the test setup is so complete that 2,000 different readings of temperature and pressure throughout the gas turbine during a 7-hour test period was reported to the visitors as being normal procedure.

The gas turbine operates much the same as a steam turbine, except that it uses hot air instead of steam to spin the turbine blades, and thus eliminates the necessity of boilers, condensers, and complicated steam lines, all of which occupy valuable space in naval vessels. The Navy also is interested in the fact that the gas turbine cycle can be operated at much higher temperatures than the practical limitation of 850 degrees Fahrenheit for shipboard installations now prevailing in steam turbine construction. This can be translated into less weight, less space, higher thermal efficiency than the steam turbine, thus increasing the cruising range of Navy ships.

"Although this gas turbine plant has been developed as a Navy project, it has characteristics applicable for both land and marine use," according to Doctor J. T. Rettaliata, consulting engineer for gas turbines at the Allis-Chalmers Company and director of the mechanical engineering department at the Illinois Institute of Technology. "Engineers" he continued, "regard it as a highly significant step in development of what has been called the fourth prime mover—following the steam engine, the steam turbine, and the internal combustion engine. Optimistic engineers in recent years have forecast eventual use of gas turbine power plants to generate electric power for industrial plants and to serve as propulsion power for planes, ships, and locomotives."

Gas turbine research and testing will continue at the Naval Engineering Experiment Station at Annapolis. When the new Engineering Experiment Station building is completed in July, all Navy gas turbine research will be centered at Annapolis.

**Signal Corps Research at Princeton.** A two-year contract entailing the expenditure of $100,000 for fundamental research in high polymer chemistry and engineering in plastics has been awarded Princeton University by the United States Army Signal Corps. The work will be entrusted principally to advanced students under the direction of a plastics committee representing the departments of chemistry, physics, chemical, electrical, and mechanical engineering. The school of engineering at Princeton University offers a recently approved graduate curriculum in plastics leading to an advanced engineering degree. Candidates for the degree must complete a minimum of two terms of five courses each, among which the following are prescribed: properties of plastics, plastic product and equipment design, electrical measurements, chemical engineering of high polymers, and high polymer chemistry. Work on the Signal Corps research project will supplement this program, and those so engaged will work as research fellows.

**ASHVE Purchases Research Laboratory.** To provide adequate research facilities for serving the entire heating, ventilating, and air conditioning industry as well as associated industries, the American Society of Heating and Ventilating Engineers has opened a new research laboratory in Cleveland, Ohio. The site of the new laboratory contains a substantial dwelling with a large two-story brick auditorium type building attached. The brick building, which is 58 by 125 feet on its foundations houses the laboratory building. The Society's research program is in its 27th year.

# INDUSTRY.....

## High Frequency Radio Tested for Railroad Use

A three-day test of high frequency railroad radio communications to demonstrate the most effective methods by which railroad mobile radio techniques could enable yardmasters to keep in constant touch with all locomotives under their direction was held recently by the Detroit, Toledo, and Ironton Railroad in conjunction with the Farnsworth Television and Radio Corporation. The Detroit–Dearborn, Mich., area was chosen as the site for the test because engineers believed that equipment meeting requirements in this congested traffic center would be effective anywhere in the world.

For the tests, high frequency transmitter–receiver equipment was installed in the railroad yardmaster's office and in the cabs of a steam and of a Diesel-electric locomotive. Also an unattended satellite booster transmitter–receiver was erected in the Ford Motor Company plant, Dearborn, to extend the range of the yardmaster's primary transmitter and to eliminate "dead spots" caused by the terrain or structural obstructions in the path of the high frequency wave radiation. At one point in the demonstration a steam locomotive and coach passed through a ten-mile series of steel-reinforced concrete arches standing at three-foot intervals. These obstructions would interfere seriously with standard broadcast signals but would not affect the very high frequency tests.

## FPC Authority Sought for Pipe Line to Transport Gas

Application for authority to construct the necessary conversion facilities and to operate the Big Inch Pipe Line to transport natural gas to New York, New Jersey, and eastern Pennsylvania has been made by Big Inch Gas, Inc., to the Federal Power Commission. An offer to the War Assets Corporation of $40,000,000 for the Big Inch is made in conjunction with an offer of Big Inch Oil, Inc., to purchase the Little Big Inch for transportation of petroleum products.

Conversion, which is expected to begin immediately upon acquisition of the pipe line, will consist of cleaning and testing the line, installing 13 or more compressor stations with over 100,000 aggregate horsepower, and constructing delivery lines to consumers. Upon completion of construction, the line would be put into operation with a capacity of approximately 275,000,000 cubic feet of gas daily.

According to a report of the Surplus Property Administration, the Big Inch pipe line is a welded steel 1,340-mile line, 24 inches in diameter (except in a few instances), which runs from Longview, Tex., to Linden, N. J. Built during the war, it replaced tanker delivery of crude oil to the East to eliminate loss through attack by enemy submarines. The Little Big Inch, which is to be operated as a petroleum products transportation pipe line, is a 20-inch line extending from Texas City, Tex., to Linden. It also was constructed during wartime to replace tanker delivery of petroleum products.

**Somervell Receives Post.** General Brehon B. Somervell, retired commander of the United States Army Service Forces during World War II, has been elected president of Koppers Company, Inc., Pittsburgh, Pa. The company builds and operates coke and other coal by-products plants in 24 states where such products as road tars, wood preservatives, and waterproofing materials are made. J. P. Williams, Jr., who has been acting as president and chairman of the board since the death of J. J. Tierney in 1944, will continue as chairman.

**Nuclear Physics Course for Employees.** A special graduate course on the introduction to "atomistics" and applied nuclear physics has been established for the personnel of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., in co-operation with the Illinois Institute of Technology. The 16-week course, which meets for a two-hour session one night each week, presents a series of guest lecturers including Doctor Don Kerst, who was instrumental in the practical development of the betatron; Doctor G. M. Almy, professor of physics at the University of Illinois; and physicists from the Universities of Chicago and Wisconsin.

## Metal Lens Developed for Microwave Transmission

A metal lens capable of focusing radio waves as an optical lens focuses light has been developed at the Bell Telephone Laboratories, New York, N. Y. The new lens is expected to find its most widespread application in microwave radio relay systems such as the New York to Boston channel now under construction. These systems similar to systems developed for the Armed Forces during the war, are designed primarily as adjuncts to the telephone network but may find additional use in transmitting pictures, radiobroadcasts, and television programs, as well as in the peacetime development of radar.

A major problem in the development of microwave communication has been that of transmitting and receiving the wave energy in the form of a narrow beam like that of a searchlight. These very short waves do not follow the curvature of the earth but shoot off into space and so transmission over long distances requires the use of relays. The new metal lens produces the sharp beam necessary to obtain short range transmission between successive relay stations with the least interference.

The lens operates on a principle comparable to that of a simple convex magnifying glass which can focus the sun's rays to burn a hole in a sheet of paper. The utilization of this principle is possible because radio waves are of the same electromagnetic nature as light waves. To overcome the necessity for the huge lens called for by the greater length of radio waves, a system of metal plates is employed which duplicates the action not only of convex and concave lens but also of other optical devices such as half and quarter wave plates and prisms.

Design and development of the metal lens was under the direction of Doctor Winston E. Kock who in 1938, was chosen by Eta Kappa Nu as the outstanding young engineer of the year. Doctor Kock was the third man to be so honored.

## Westinghouse International Forms Education Department

Formation of an education department which will act as liaison agency for the technical training of foreign students at the Westinghouse corporation and which will conduct courses abroad for the benefit of foreign associates of the company has been announced by the Westinghouse Electric International Company, Pittsburgh, Pa.

The immediate task of the new department will be the supervision of the training of 500 students from China and Mexico. Of these 300 will be selected by the National Resources Commission of China over a five year period and 200 are to be picked by the Industria Electrica de Mexico, S. A. The students will attend the student engineering course offered by the Westinghouse Electric Corporation, East Pittsburgh, Pa.

An experimental program of setting up courses abroad where representatives of the company's foreign distributors and allied companies can study conveniently also has been inaugurated. A ten-week course in air conditioning and commercial refrigeration will be given in Havana, Cuba, for South American and Caribbean representatives.

In addition to these activities the department will aid in picking future engineers for the International company from American students completing the student course and will form a central bureau for distribution of special electronic and electrical equipment for science laboratories of foreign educational institutions.

## Digest of Motion Study Films Made by Management Society

A summary of the motion study records filmed by Frank B. Gilbreth, father of motion study, between 1905 and 1924 has been made available, after five years of preparation, to universities and business and industrial organizations by the Chicago chapter of the Society for the Advancement of Management.

Among the more significant studies included in the digest film are: the brick laying project which led to motion study, factory operations which led to the development of motion study principles, the first studies of surgical operations, Frederick Taylor's pig iron carrying experiment, and a study of skill by the cyclegraph technique. The 1,200 foot 16-millimeter film, which is titled "Original Films of Frank B. Gilbreth," may be obtained from the Chicago chapter of the Society for $75. As the chapter is not staffed to maintain loan service, anyone wishing a preview of the film must make arrangements through the Bureau of Visual Instruction, University of Iowa, Iowa City. The university's film library rate is $4.

## RMA and Educators Set School Radio Standards

A program for standardizing radio and sound amplifying equipment in United States schools has been approved by a joint committee of radio manufacturers and educators, the Radio Manufacturers Association has announced.

Plans are now in the hands of the RMA engineering and sound system sections for final drafting of a set of minimum standards for school radio and sound facilities to protect the institutions from inadequate equipment and to permit free exchange of radio educational material.

Tentative specifications were drawn and approved at a recent meeting in Cleveland of the RMA school equipment committee and representatives of the National Education Association, the Association for Education by Radio, and the United States Office of Education. The specifications cover five classifications of school radio and sound amplifying equipment—central program distribution systems, classroom receiving sets, portable transcription players, speech input units, and recorders.

**George W. Bacon Retires.** George Wood Bacon, one of the founders and lately chairman of the board of the engineering firm of Ford, Bacon and Davis, Inc., retired from active participation in the organization on March 12. Mr. Bacon, who is 77, founded the firm shortly after his graduation from Cornell University in 1892.

**Radiotelephone Permits.** During the month of March, 221 railroad applications were received by the Federal Communications Commission from railroads planning to install radiotelephone systems of the portable-mobile type. Several railroads have received permits in the meantime under the new FCC rules and regulations for permanent installations of this type of equipment.

# OTHER SOCIETIES •

## IES Issues New Edition of Street Lighting Code

Recommendations of adequate illumination needed for streets and highways as a means of reducing the high traffic accident and crime rate are made in the new edition of the street lighting code, "Recommended Practice of Street and Highway Lighting," just published by the Illuminating Engineering Society.

## Future Meetings of Other Societies

**American Chemical Society.** National Chemical Exposition, September 10–14, 1946, Chicago, Ill.

**American Society for Testing Materials.** Annual meeting, June 24–28, 1946, Buffalo, N. Y.

**American Society of Mechanical Engineers.** Annual meeting, June 17–20, 1946, Detroit, Mich.

**American Welding Society.** Annual meeting, November 17–22, 1946, Atlantic City, N. J.

**Canadian Electrical Association.** Annual meeting, June 26–28, 1946, Banff, Alberta, Canada.

**Edison Electric Institute.** June 3–5, 1946, New York, N. Y.

**Great Lakes Power Club.** Spring meeting, May 24, 1946, Chicago, Ill.

**Illuminating Engineering Society.** National convention, September 18–21, 1946, Quebec, Quebec, Canada.

**Instrument Society of America.** Exhibit and conference, September 16–20, 1946, Pittsburgh, Pa.

**International Conference on Large High-Voltage Networks.** June 27–July 6, 1946, Paris, France.

**National Electrical Manufacturers Association.** June 17–19, 1946, Hot Springs, Va.

**National Electrical Contractors Association.** Annual meeting, October 14–18, 1946, Atlantic City, N. J.

**National Electronics Conference.** October 3–5, 1946, Chicago, Ill.

**National Fire Protection Association.** June 3–6, 1946, Boston, Mass.

**Pennsylvania Electric Association.** Spring meeting, May 28–29, 1946, Harrisburg, Pa.

The result of four years research, the code is used by municipal and utility officials in evaluating the efficiency of street lighting systems and in planning new installations. In stressing the importance of the code, the society notes that two thirds of all traffic fatalities occur during hours of darkness when there is only one third of the volume of daytime traffic.

Because the amount of illumination needed for streets and highways is governed by traffic conditions, the code classifies all roadways according to volume of vehicular and pedestrian traffic. A heavy traffic thoroughfare with a vehicular count of 1,200 to 2,400 vehicles, during a maximum night hour with heavy pedestrian traffic, will need a minimum of 1.2 foot-candles of light intensity for traffic safety, whereas a very light traffic thoroughfare, which generally includes residential streets, will need only 0.2 foot-candles.

The lamp size and luminaire needed to furnish the recommended intensity of light is given, with the mounting height and spacing based on the width of thoroughfare and reflectivity of the pavement surface. Situations such as curves, intersections, railway crossings, bridges, and dual highways also are given consideration.

The first edition of the code published in 1940 was used in planning installations of safety lighting in Detroit, Hartford, Salt Lake City, and Los Angeles.

# JOINT ACTIVITIES

## Navy Cites ASA for Safety Work

The American Standards Association has been presented with the United States Navy's Certificate of Achievement "in recognition of specialized accomplishment on behalf of the United States Navy and of meritorious contribution to the national war effort." The ASA is the fourth organization in the United States to be given this award.

The citation reads as follows:

"This organization, upon whose Executive Board the Navy has representation, performed a commendable service to the Navy through the preparation and development of Safety standards, codes, and specifications, many of which have been adopted by the Navy. This program of the American Standards Association speeded up the process of the development and preparation of such codes which otherwise would have involved considerable research and, most important, would have taken considerable time to prepare and develop, had the Navy undertaken such tasks without the aid, guidance, and assistance which the American Standards Association so ably rendered."

# EDUCATION • • •

**Summer Management Course at Iowa.** The eighth annual summer management course will be held at the University of of Iowa, Iowa City, from June 10 to June 28. The course is designed especially for managers, foremen, industrial engineers, methods, cost accountants, and other executives. The study plan combines fundamental training with practical applications and attention will be given to procedures of conducting factory training programs in the fields covered. Advance registration is required and enrollment is limited. Registrants are expected to be college or university graduates or their equivalents. Tuition and fees for the course are $150 plus living expenses.

## First Award Established for Engineering Education

Establishment of a new annual award of $1,000 honoring the college or university teacher adjudged to have contributed most to the successful teaching of engineering students was announced recently by the Society for the Promotion of Engineering Education. To be known as the George Westinghouse Award in Engineering Education, it was endowed by the Westinghouse Educational Foundation in commemoration of the 100th anniversary of the birth of the inventer.

Presentation of the first award will be made in June 1946, and nomination forms have been sent to the deans of the 165 engineering schools of the United States and to the officers and executives of the committees of the society and related national engineering societies. "The task of the committee on the award will involve pioneering in methods of appraising outstanding teaching. The committee already has planned its procedures with great care, and the hope is high for a valid appraisal of distinguished contributions and for success in the encouragement of teaching achievement," the announcement stated.

Doctor Homer L. Dodge, president of Norwich University, Northfield, Vt., is chairman of the committee on award. Other members are:

Doctor Harry S. Rogers, president of the Polytechnic Institute of Brooklyn; Doctor H. P. Hammond, dean of the School of Engineering at Pennsylvania State College; Doctor W. R. Woolrich, dean of the School of Engineering at the University of Texas, Austin; Professor R. T. Birge, University of California, Berkeley; Professor W. Otto Birk, University of Colorado, Boulder; Professor J. W. Cell, North Carolina State College, Raleigh; Professor H. F. Croft, State University of Iowa, Iowa City; Professor H. E. Dycho (F '42) the University of Pittsburgh; and C. A. Powel (F '41) representing the Westinghouse Educational Foundation.

# LETTERS TO THE EDITOR

**INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.**

## Electrical Essays for Recreation

*To the Editor:*

My good friend, K. L. Hansen, in his letter (*EE, Feb '46, p 95*) shows that in the example described there, the concept of generating a voltage by the cutting of magnetic lines furnishes the correct answer (no cutting takes place) while the concept of having the voltage generated by a change of flux associated with a loop would lead us to the prediction that there will be a voltage generated during the time that the clip-like loop is slipped over the legs of the magnet (see figure on page 95).

The proponents of the "cutting concept," to date, have not been able to give an explanation satisfactory to this writer of how a transformer operates. To be sure, I have listened to the argument that, since the flux in the core is zero at a given instant, but has reached a maximum one quarter cycle later, the magnetic lines can have gotten into the core only by jumping from space (where they presumably were waiting for the call) into the core, and in so doing must have "cut" through the turns placed around the core, but this seems to me a rather far-fetched explanation. No such mental gymnastics are required when we stick to Maxwell's equation $e = n(d\phi) \div (dt)$. In a betatron, for instance, electrons are accelerated in an orbit which does not even consist of a conductor, simply by the rate of change of flux associated with this orbit. In this case: who cuts what with what, where, and how?

But while the "cutting" concept in this writer's opinion at least, falls down in explaining the operation of as common a piece of electric equipment as a transformer, the "change of flux linkage" concept is easily applicable even in those cases where the "cutting" concept seems to be a "natural." Consider in Figure 1 the single conductor moved through a constant magnetic field in the direction shown. As one of my teachers used to say: "Nobody has ever measured a voltage without completing a loop," and, if this is applied to the case shown, it is obvious that the flux associated with the loop formed by the conductor, the measuring leads, and the instrument changes by exactly the same number of

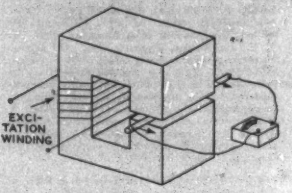
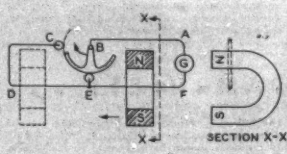


Figure 1 (above)

Figure 2 (left)

Figure 3 (below)




lines as are "cut" by the motion of the conductor. Both concepts, therefore, give the same result. But now assume that the magnetic field in the air-gap is *not* constant, in other words, that the exciting current changes with time. Though it is possible to resolve the voltage induced in this case in two components, a voltage of "transformation" and of "motion," it seems so much simpler to determine the rate of change of the total flux, which then will give us the total induced voltage.

In Figure 2 the cross section of a coil rotating in a magnetic field is shown. Here again, for the case of d-c excitation of the field, the voltage can be considered as induced either by the cutting of the magnetic lines by the two individual coil sides, or by the flux associated with the coil changing with the rotation of the coil. It was the cutting concept, however, that misled the young inventer mentioned in my earlier letter (*EE, Oct.' 45, p. 381*) into believing that he could induce a direct voltage in the coil by exciting the field synchronously, that is, by seeing to it that when coil side *A* was coming around to the lower position, this pole had become a north pole. He overlooked the fact that at the instant when the coil is in a horizontal position, it forms a transformer with the a-c exciting winding of the main field; that at this instant the field passing through the coil changes and, therefore, produces a voltage, even if no lines are being cut at this instant. Mr. Hansen's explanation of the resulting double frequency by resolving the single-phase field into two oppositely rotating fields, is, of course, the simplest way; but, since this resolution is more or less a mathematical concept only, the explanation employing the "change of flux" seems to be a more fundamental one, even if it is not the simpler one.

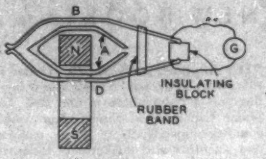



Figure 4

But where does the rate-of-change-of-flux-linkage concept leave us in the case of the problem cited by Mr. Hansen? I am not ashamed to admit that, when this tricky arrangement was first shown to me a few years ago, my immediate reaction was that there would be a voltage induced while the loop is pulled off the magnet. More careful analysis led to the following steps: consider the circuit shown in Figure 3 as lying in the plane of the paper, while the two cross sectioned rectangles represent the two legs of a horseshoe magnet penetrating the paper, so that the flux of the magnet penetrates the loop *ABEF*. Now let the rotary switch be operated in the direction indicated; this enlarges the loop to *ABCDEF* without opening the circuit. There is no reason why a voltage should be induced during the switching operation. Now move the magnet horizontally to the dotted position. This movement does not change the flux linking with the loop *ABCDEF*, and, therefore, no voltage will be induced during the movement. Next, return the rotary switch to the position as shown. Again no voltage will be induced, because, while it may seem that the flux has disappeared out of the original loop, we have accomplished it by transferring it to another section and then pinching off this section; in other words, we were not always dealing with the same loop.

Now consider Figure 4, which is essentially the same as that shown by Mr. Hansen, except that the copper strip *A* has been placed around the leg of the magnet. The flux of the magnet passes through the loop *BCD* in the position shown. When we now move this loop to the right, it will spread open at *C* and slide over strip *A*. During the sliding the flux penetrating the complete loop, which now consists of two parts, does not change. Finally, the loop *BCD* can be pulled clear of *A*, with zero flux through it. While a closed circuit has been maintained at all times, nevertheless, the flux passing through a loop containing the instrument never was changing at any time, it was taken out of the original loop by pinching of part of the final loop.

These two examples show that a magnetic flux may be taken out of a loop without inducing a voltage, if commutation is resorted to. This is obviously the case when the clip is slipped over the leg of the magnet itself, where a continuous commutation takes place during the sliding of the clip.

WALTHER RICHTER (F '42)

(Electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.)

*To the Editor:*

In commenting on Mr. Richter's letter in the October 1945 issue of *Electrical Engineering*, I had no intention of becoming a participant in a controversy over concepts of electromagnetic induction. I am quite neutral in the matter and merely wished to call attention to a forceful argument presented many years ago against the unqualified acceptance of the "change of flux" theory.

The fundamental requirement for induction of an electromotive force is that the conductor and the flux be in relative motion at right angles to one another. Whether the motion is looked upon as the flux being cut by the conductor, or as increasing or decreasing within a closed loop, seems to me to be immaterial.

Mr. Richter concedes that flux can be made to enter or leave a closed loop without inducing a voltage when commutation is resorted to. That is, of course, when cutting of flux is avoided. Commutation usually consists of transfer of current from one part of an electric circuit to another by means of a sliding contact. It is interesting to observe that when such contacts are employed the reverse of that phenomenon also can take place, namely, the induction of a voltage without flux increasing or decreasing within a closed loop.

In Figure 1 the solid metal disk, a portion of the shaft, the brush bearing on the shaft, the circuit containing the ammeter, and the brush bearing on the periphery of the disk constitute a closed loop. When the disk is rotated, a voltage is generated as shown by the ammeter.

The voltage generated is direct current and, when the direction of rotation is reversed, the polarity of the generated voltage is reversed. On the basis of the "change of flux" theory that means that the flux in the loop must be continually increasing in one case and continually decreasing in the other. Obviously such is not the case.

I believe it is even more difficult to account for this phenomenon on the basis of the "change of flux" theory without re-

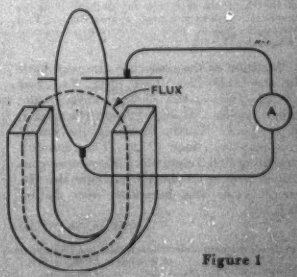



Figure 1

sorting to a far-fetched explanation than it is to explain transformer action between two stationary coils by the "cutting of flux" theory.

K. L. HANSEN (F'34)

(Consulting electrical engineer, Milwaukee, Wis.)

## Atmosphere Penetration by Electromagnetic Waves

*To the Editor:*

In reading the most excellent March issue of *Electrical Engineering* I came across the news item, "Message to Moon Proves Atmosphere Penetration," on page 140. It contains the statement:

> The principal significance of the radar-to-the-moon tests recently conducted by the United States Army Signal Corps, according to Major General Harry C. Ingles, Chief Signal Officer of the Army, is that they demonstrated for the first time that radio waves in the very high frequency band will penetrate completely the ionosphere, the celestial void, and whatever form of atmosphere may surround the moon.

Aside from the fact that electromagnetic waves, called light, have been penetrating the "celestial void" for eons, I wonder if the discovery of Karl G. Jansky in 1932 that radio waves of short wave length were coming to the earth from the Milky Way, which is a little farther than the moon, did not also prove that high frequency radio waves penetrate the ionosphere, the celestial void, and the atmosphere of the earth?

Karl Jansky's discovery was published in the October 1933 *Proceedings* of the Institute of Radio Engineers, pages 1387–98, under the title, "Electrical Disturbances Apparently of Extraterrestrial Origin." The following is quoted from that paper:

> Electromagnetic waves of an unknown origin were detected during a series of experiments on atmospherics at high frequencies. Directional records have been taken of these waves for a period of over a year. The data obtained from these records show that the horizontal component of the direction of arrival changes approximately 362 degrees in about 24 hours in a manner that is accounted for by the daily rotation of the earth. Furthermore the time at which these waves are at a maximum and the direction from which they come at that time changes gradually throughout the year in a way that is accounted for by the rotation of the earth about the sun. These facts lead to the conclusion that the direction of arrival of these waves is fixed in space; that is, that the waves come from some source outside the solar system. Although the right ascension of this source can be determined from the data with considerable accuracy, the error not being greater than ±7.5 degrees, the limitations of the apparatus and the errors that might be caused by the ionized layers of the earth's atmosphere and by the attenuation of the waves in passing over the surface of the earth are such that the declination of the source can be determined only approximately. Thus the value obtained might be in error by as much as ±30 degrees.

Mention of the discovery also was made in the *New York Times*, the *New York Herald Tribune*, the *Chicago Tribune*, and other papers. Doctor Stetson discusses it in his book, "Earth, Radio and the Stars," chapter 16, page 233. The *Scientific Journal* of Bell Telephone Laboratories contained papers on the subject, and the discovery once was broadcast over station WEAF.

C. M. JANSKY (F'32)

(Professor emeritus of electrical engineering, University of Wisconsin, Madison, Wis.)

# NEW BOOKS . . .

**"The Engineer in Society."** Under this title, John Mills, who retired a year ago as director of publications of the Bell Telephone Laboratories, directs some pungent comments specifically to young engineers and scientists and incidentally to anyone else who happens to get in the way. Reflecting his 45 years of personal experience in dealing with things and with people, he believes that "Engineers as a class are too modest. Even as individuals, they are rarely boastful of their ability or their accomplishments. They do not advertise themselves or their profession. It should not have required the development of an atomic bomb to direct attention to the political importance of science and engineering. Nor to emphasize for scientists and engineers their relationship to the world society of which they are a part. These recognitions are by-products which may prove to be more influential than the bomb itself. The immediate problem before engineers and scientists in industry is an engineering study of their class relationship to society." In spite of the fact that popular lists of "Noteworthy persons" traditionally list monarchs, warriors, artists, actors, and writers, while engineers remain largely in anonymity, Mr. Mills thinks that the engineering profession is not in the doldrums, but "is near the top and with potentiality yet unrealized, which can and should be released by the coming generation." Based upon his long and intimate experience with industrial scientists, Mr. Mills advances characteristically challenging ideas about aptitude tests and the business of fitting the right man to the right job; about "scientists gone executive," and the salaries of engineers and scientists; about woman's part in engineering work; about the question of an over-all organization of scientists and engineers. He undertakes to reveal certain of the road blocks that must be passed before engineers and scientists find their most serviceable and mutually satisfactory position in society. By John Mills. D. Van Nostrand, New York, N. Y. 1946. 196 pages, 7½ by 8¼ inches, cloth, $2.50.

**The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.**

RAILROAD AVENUE. By F. H. Hubbard. McGraw-Hill Book Company, Inc., Whittlesey House Division, New York, N. Y., and London, England, 1945. 374 pages, illustrated, 9 by 6 inches, cloth, $3.75. The author of this book on railroading and railroaders has collected his material with an eye for the entertaining. Among the stories and legends are authoritative versions of old favorites, as well as a variety of lesser-known and obscure items from the full history of the period. Songs and poems from and about railroad life are reproduced, and there is a vocabulary of "railroad lingo." The book is well illustrated by contemporary portraits, drawings, and photographs.

BASIC ELECTRICAL ENGINEERING, Circuits, Machines, Electronics. By A. E. Fitzgerald. First edition, McGraw-Hill Book Company, New York, N. Y., and London, England, 1945. 443 pages, illustrated, diagrams, charts, tables, 9 by 5¾ inches, cloth, $3.75. This new textbook presents an integrated treatment of circuit theory, electric machinery fundamentals and applications, and engineering electronics together with discussion of instrumentation and of automatic-control applications in research and industry. It is intended for students who have had a course in college physics and have some experience in simple d-c theory.

TELEVISION SIMPLIFIED. By M. S. Kiver, D. Van Nostrand Company, New York, N. Y., 1946. 375 pages, illustrated, 8¼ by 5½ inches, cloth, $4.75. A complete, practical description of modern television is presented in step-by-step fashion without involved theory or mathematics. The author proceeds from the analysis of circuits and the operating fundamentals of frequency modulation to the repairing of television sets and the explanation of an actual trouble-shooting system. The book is intended for radio workers, owners and service men, and all who are interested in television and its opportunities.

RADAR. By O. E. Dunlap, Jr. Harper and Brothers, New York, N. Y., and London, England, 1946. 208 pages, illustrated, 8¼ by 5¼ inches, cloth, $2.50. Written for the layman, this book traces the history of radar from the early reflected wave experiments of Hertz and Marconi and presents a simple explanation of its basic features. The range and likely worth of various peacetime applications are considered, and a glossary and bibliography are appended.

# PAMPHLETS . . .

**The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.**

**Report PB-15058.** A description of experiments in diversity reception. Office of the Publication Board, Department of Commerce, Washington 25, D. C. Photostat copy, $3; microfilm copy, 50 cents.

**Report PB-15055.** Data on European radio tubes, military and commercial. Office of the Publication Board, Department of Commerce, Washington 25, D. C. Photostat copy, $5; microfilm copy, $1.

**Weston Engineering Notes.** Bimonthly publication. Anyone whose interests include instrumentation problems may be placed on the mailing list. Address John Parker, editor, Weston Electrical Instrument Corporation, Newark 5, N. J.

**A Guide to the Literature on the History of Engineering Available in the Cooper Union Library.** Bulletin 28. This bulletin is an inventory of books and articles in the library which are likely to be of interest to the student of the history of science and engineering. In addition it is hoped that it may prove of value to the engineering librarians of other colleges as a check list to help present the historical material of their libraries. The Librarian, Cooper Union Library, Cooper Square, New York 3, N. Y., 46 pages.

**Philips Research Reports.** A bimonthly journal edited by N. V. Philips Gloeilampenfabrieken of Eindhoven, Holland. Subscriptions are handled in the United States by Elsevier Publishing Company, Inc., 215 Fourth Avenue, New York, N. Y. Yearly subscription $5.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

# Application of the Betatron to Practical Radiography

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**Synopsis:** The development of the betatron, which accelerates electrons by magnetic induction making possible the production of higher energy X rays than is practical by the direct application of the accelerating potential, has extended the range of X rays indefinitely, the only limit being the size of the machine. Tests with the betatron have shown that the best energy for medical and radiographic use is 20 mev (million electron volts). The development of this machine from a physics laboratory instrument to an industrial machine is described, as well as the radiographic properties of the X rays produced.

THE FIRST successful type of betatron, invented by Doctor D. W. Kerst at the University of Illinois, is an induction electron accelerator which means that electrons are accelerated by magnetic induction instead of by direct application of high potential. The result is that the voltage insulation is not the limiting factor in the acceleration of the electrons, and they can be given energies not previously obtainable by any other man-made means.

In the betatron an alternating magnetic field holds the electrons in a stable circular orbit within an evacuated annular chamber called a "donut," and the increasing field produces a force on the electrons which accelerates them to high velocities. A special field contour is necessary to hold the electron in its orbit as its mass changes relativistically with increasing velocity.

## Development of the Theory

The idea of acceleration of electrons by magnetic induction was the subject of experiments conducted by many scientists. J. Slepian stated the general principle in his patent[1] issued in 1927, but he apparently did not develop his calculations to the point of producing a satisfactorily workable machine. Wideroe[2] was the first to show that the necessary field condition for a stable equilibrium orbit is $\phi_0 = 2\pi r_0^2 H_0$ where

$r_0$ = radius of equilibrium orbit
$\phi_0$ = flux within orbit
$H_0$ = field at the orbit

This was verified by Walton[3] and later referred to by Steenbeck[4] as the 1:2 relation as the flux within the orbit is twice as much as would be obtained if the magnetic field were uniform in space. Steenbeck stated that the field in the region of the orbit should be $H \propto 1/r^n$, where $0 < n < 1$. Kerst and Serber[5] verified the calculations of Wideroe and Walton and also developed the equations for transient phenomena in the magnetic field. Kerst[6] was the first to place an injector in the magnetic field for supplying electrons at a substantial initial velocity to the orbit. Several of the earlier investigators had tried to inject electrons from outside the magnetic field tangentially to the orbit but had not been successful. Steenbeck placed a heated filament in the magnetic field, but provided no means of directing the electrons emitted or of giving them an initial velocity. The injector as developed from the one used by Kerst is shown in Figure 1, and consists of a heated filament, grid, and surrounding plate so that the stream of electrons is ejected by a negative pulse applied to the filament (the plate is grounded to prevent its disturbing the orbit by its electrostatic field). The grid is a solid piece of metal used to minimize the electron bombardment of the plate and is connected to one side of the filament.

On the basis of the calculations made by Kerst and Serber, Kerst[6,7,8] was able to construct the first betatron to operate successfully in a practical manner.

Kerst and Serber also calculated the paths of electrons which would oscillate about the equilibrium orbit while the focusing forces are damping the oscillation. From their calculations they could predict the best value for $n$ so that the most electrons would miss the injector on the later revolutions and be focused to the orbit.

The Kerst type of betatron is essentially a three-legged transformer with the accelerating field formed in an air gap by

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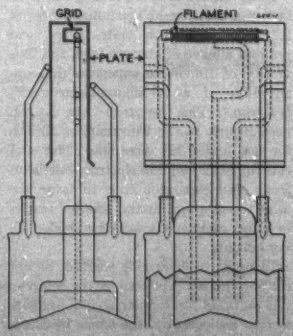
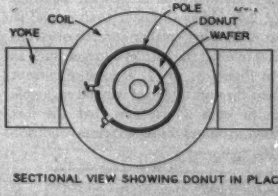
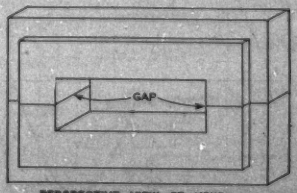



Figure 1. Injector




SECTIONAL VIEW SHOWING DONUT IN PLACE




PERSPECTIVE VIEW OF YOKE

Figure 2. Betatron magnet

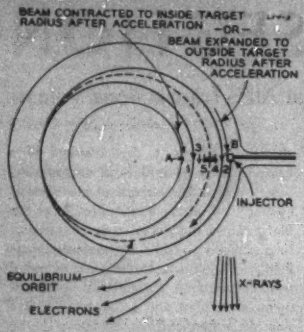



**Figure 3. Sectional view of donut showing positions of injector and targets as well as electron paths**

radially symmetrical poles in the center leg as shown in Figure 2. Coils shown provide the necessary flux when a voltage is applied to them. In practice a sinusoidal voltage is applied as this is the simplest means of providing the time-increasing field, although only one quarter of each cycle is utilized in the acceleration of the electrons. The donut and injector are shown in position in Figure 3 which also illustrates the various electron paths during focusing, injection, and expansion.

In operation, electrons are injected when the flux wave is at point $A$ as shown in Figure 4. They are accelerated as the flux increases until point $B$ is reached where they are caused to deviate from the equilibrium orbit by either of the two following means: (1) the center of the pole is allowed to saturate with the result that $2H_0$ increases faster than $\phi/\pi r_0^2$ so that $r_0$ becomes smaller and the electrons spiral in until they strike a target, such as $A$ in Figure 3; or (2) a pulse of current is sent through a turn of wire on each pole face in such a direction that the flux caused so upsets the equilibrium condition

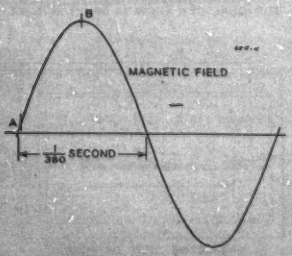



**Figure 4. Flux wave**

that $r_0$ becomes larger causing the electrons to spiral out and strike a target ($B$ in Figure 3) mounted on the back of the injector. Kerst, in his original machine, used the first method as it is simpler and does not require a carefully timed electronic tube circuit as does the beam expansion method.

## The Production of X Rays

When the high energy electrons strike the target, X rays are produced, the greatest intensity of which emerge from the donut in a narrow cone in the direction which the electrons are traveling at that time. As the conversion of the kinetic energy of the electrons to X rays is higher for high energies than low (theoretically 65 per cent of the electron energy is converted to X rays at 20 million electron volts as compared to a few per cent at

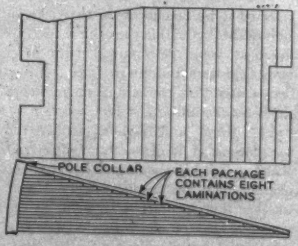



**Figure 5. Details of pole laminations**

1 million electron volts) very little of the energy is absorbed by the target, so that the target remains relatively cold and does not deteriorate with use.

## Development

After successfully operating his first betatron which had a maximum energy of 2.3 million electron volts, Kerst was granted a leave of absence from the University of Illinois to supervise the construction of a 20-million-electron-volt betatron.[9] This betatron was loaned permanently to the University of Illinois for use under his direction. This and subsequent 20-million-electron-volt betatrons used expansion coils to cause the orbit to spiral out as this method results in higher maximum energy and higher X-ray output.

In order to determine whether or not the X radiation produced by the betatron was suitable for industrial use in thick section radiography, the Office of Scientific Research and Development ap-

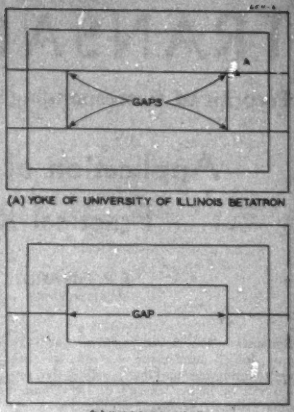



**Figure 6. Betatron yoke**

pointed Kerst as official investigator and allotted funds for the work. When the investigation showed that the 20-million-electron-volt betatron could be used to great advantage in thick section radiography, OSRD authorized and financed the further work necessary to develop the betatron for industrial use, including the building of one machine. Kerst and his staff from the University of Illinois then obtained the co-operation of the Allis-Chalmers Manufacturing Company in this development in order to make the betatron available to war projects. The general details, such as size of pole and dimensions of yoke, are practically the same as described by Kerst with the major improvement being made in the mechanical construction of the betatron, and in the development of the donut.

One of the major improvements made in this development was in the improved construction of the pole. The simplest way to construct a radially symmetrical pole is by making pie-shaped sectors of various lengths as shown in Figure 5 with several sectors making a complete pole. In the first 20-million-electron-volt betatron, these laminations were held together by a thermal setting resin which proved in operation that it was not strong enough to hold against the magnetic forces present, and gradually the pole developed short circuits until the beam was disrupted and the X-ray yield materially decreased. By careful welding and insulating, a very rigid pole was constructed. One set of these poles has been installed on the University of Illinois machine for over a year, and has been operated as many hours as

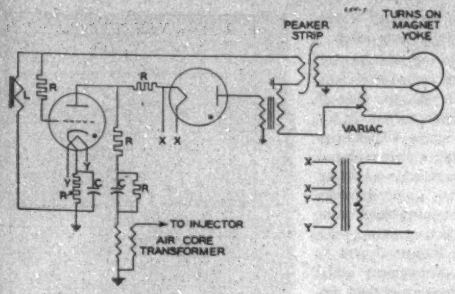



Figure 7. Injector circuit

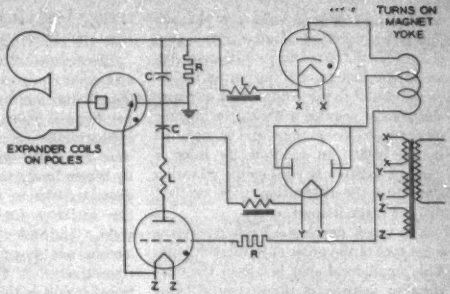



Figure 8. Expander circuit

the original set, but shows no signs of going bad. In fact, the yield is now higher than ever was obtained with the original machine. Also, the pole laminations were cut on a die which assured a very smooth and radially symmetrical pole.

The coils on the commercial machine are held very rigidly in place and air ducts provided to aid in cooling. Because of the high leakage flux caused by the air gap for the accelerating field, the turns must be stranded with each strand insulated from all others by Formvar varnish and all layers wound in the same direction in order to keep induced voltages and eddy currents at a minimum.

The yoke on the University of Illinois machine was made in four pieces as shown in Figure 6A with only the weight of the steel holding them in place. By assembling in two halves as shown in Figure 6B, a much better construction was possible, and by the use of guide rods, the alignment of the poles could be made at the time of assembly with the assurance that the poles could be separated for installation of a donut and the alignment would always be the same. Then, by installing lifting jacks operated by a gear motor with chain and sprocket system the top half of the betatron could be lifted without the use of an auxiliary hoist. The construction of the yoke in two halves also will simplify the clamping necessary to make possible the mounting of the betatron for rotation of the beam should it be desired.

One of the most interesting developments made was in the manufacture of donuts. The first donuts made for the University of Illinois 20-million-electron-volt machine consisted of two short glass cylinders forming the outer and inner wall with two glass washers forming the top and bottom. These glass parts were waxed together with tubes waxed on to hold the injector and for the pump stem. The sections of glass forming the inner surface of the donut had to be sand blasted so that a suitable conducting coating could be applied. The coating was necessary so that the stray electrons not captured by the beam and striking the donut walls would be drained off and would not be allowed to build up static charges which would disturb the beam; and, at the same time, the coat must be of high enough resistance that the eddy currents induced would not disturb the beam or heat the donut too much. The main trouble with the waxed donut was that the tube could not be evacuated and then sealed off, necessitating a pumping system. Also, owing to the heat generated by the injector filament, it was necessary to blow air on the wax close to the injector stem to prevent softening of the wax with resulting leaks.

To solve the donut problems, the Ceramic Engineering Department at the University of Illinois, under a contract with OSRD, was able to develop a porcelain which was capable of having glass sealed to it and was vacuum tight. Moreover, this porcelain donut could be made by coreless casting which resulted in a fairly inexpensive product. Some development was necessary in order to coat the inside of this tube and make the glass seals, but the difficulties were overcome and donuts were produced, evacuated, and sealed-off which have been giving very satisfactory service. This resulted in the elimination of a high-vacuum pumping system on the betatron which would have been the cause of much trouble in the successful operation of betatrons in industrial radiography.

A study was made of the injector and the design and structure were improved

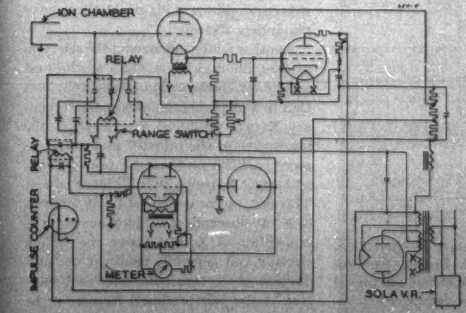



Figure 9. Exposure control circuit

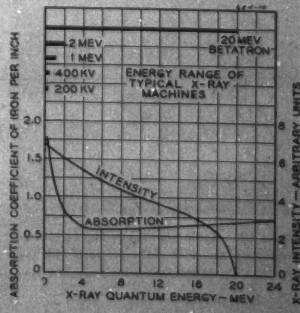



Figure 10 (right). Absorption curve for steel and theoretical X-ray spectrum at 20 million electron volts

so that an increased yield was realized. The injector, which is an electron gun, should not have too large a distance between the filament and the part of the injector closest to the orbit so that as many electrons as possible will miss the injector on successive revolutions, and be captured by the orbit. In addition, the injector must be sufficiently rigid so the vibration caused by the alternating magnetic field will not shake it apart.

The target developed made possible a focal spot of the order of 0.010 inch high. This small focal spot is one of the outstanding features of the successful betatron. If the electrons hit the back of the injector with no special target, the focal spot will be of the order of 0.050 inch high. The width in both cases is so small as not to be measurable. Calculations have been made which show that the difference in successive revolutions of the electrons as they spiral out is of the order of $10^{-4}$ centimeter so the width of the focal spot should be of the same order.

The circuits of producing the injection and expansion pulses described in Kerst's paper[3] were improved with the idea of providing a more satisfactory unit for industrial use. For example, all batteries were eliminated and tubes were replaced by others having more reliable operating characteristics to reduce to a minimum the variables for obtaining maximum yield. The present injector and expander circuits are shown in Figures 7 and 8, respectively. A very convenient additional circuit is the exposure control circuit (Figure 9) whereby the exposure in Roentgen units can be set on an impulse counter and the betatron will be shut off when it has produced the required amount of X rays.

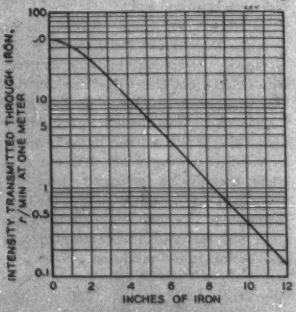



Figure 11. Transmission curve for steel at 20 million electron volts

Figure 12. Radiograph of vernier caliper between two one-inch slabs of steel with jaws open 0.010 inch

Enlargement on negative was 3.3

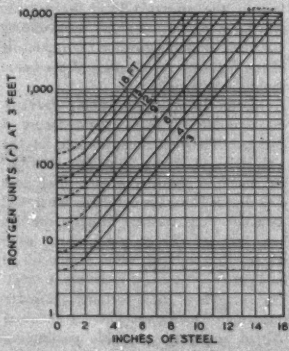



Figure 13. Exposure chart for 20-million-electron-volt X rays with Eastman industrial film, type A, 0.040-inch front lead screen, density of 2

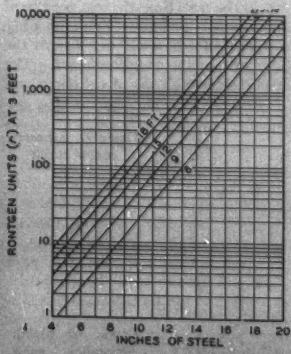



Figure 14. Exposure chart for 20-million-electron-volt X rays with Eastman industrial film, type F, 0.030-inch front lead and special intensifying screens, density of 2

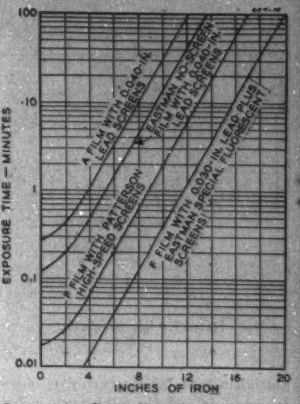

EXPOSURE TIME — MINUTES
INCHES OF IRON
A FILM WITH 0.040-IN. LEAD SCREENS
EASTMAN NO-SCREEN FILM WITH 0.040-IN. LEAD SCREENS
F FILM WITH PATTERSON HIGH-SPEED SCREENS
F FILM WITH 0.030-IN. LEAD FOIL EASTMAN SPECIAL FLUORESCENT SCREENS

Figure 15. Chart showing comparison of different films and screens

## Radiography

The betatron makes possible the radiography of thick section steel, bronze, and other heavy metals. In Figure 10 the absorption coefficient curve for iron is shown together with the theoretical intensity distribution spectrum of X rays produced by the 20-million-electron-volt betatron. From these two curves, one can see that most of the X rays produced are in the region of low absorption of steel (the absorption curves for other heavy metals are similar). In other words, the X rays in the approximate range of from 3 to 20 million electron volts are the most penetrating, and the absorption curve is nearly constant over this range which is the region of most of the X rays produced by the 20-million-electron-volt betatron. This explains the straight line transmission curve shown in Figure 11 after one or two inches of steel.

Another factor influencing the selection of 20 million electron volts as the best energy for thick-section radiography was that by going to higher energies the secondary X rays produced as a result of the absorption of the primary rays would be more penetrating than the primary rays and tend to result in a diffused image. This fact can be explained by an analysis of X-ray absorption. Unfortunately, the absorption of X rays above one million electron volt generally results in the production of electron pairs with each electron of the pair produced having on the

Figure 16. Section of radiograph of Ford model T motor. Note the damaged valve stem

average nearly one half the energy of the primary ray. These high-energy electrons lose their energy with the accompanying production of X rays which, because of the lower energy, may be more penetrating than the primary rays. The secondary rays travel in the general direction of the primary, but there is some divergence which affects the definition on the film. The 20-million-electron-volt betatron tests show that a comparatively small part of the density on the film is caused by secondary rays. With higher energy betatrons, tertiary, and higher order X rays would be produced which would be more divergent and penetrating than the secondary rays and, therefore, would produce a more diffuse image on the film.

The choice of a lower energy betatron was eliminated as the intensity for different energies at the same frequency goes as nearly the fourth power of the energy. At 10 million electron volts and 180 cycles the intensity would be 1/15 that at 20. This would necessitate a much higher frequency which would mean increased heating and higher power requirements. The heating would necessitate liquid cooling and the advantage of a lower weight machine at lower energies partially would be lost. At a lower energy output a smaller percentage of the X rays would be in the region of low absorption so that the exposure would be much longer for the same intensity. Tests at 10 million electron volts show that the fraction of density on the film contributed by the secondary rays is considerably larger than that at 20 million electron volts.

Another advantage of 20-million-electron-volt X rays is that an absolute sensitivity is obtained. This means that the size of minimum detectable flaw is the same regardless of the thickness of steel being radiographed. A 1/32-inch flaw was displayed with equal clarity through various thicknesses of steel from 2 to 12 inches on Eastman type *A* film.

In 20-million-electron-volt radiography, no blocking is necessary for variations in thickness of the specimen or around the outline. In fact, outlines may be less well defined when blocking is used.

Because the large angle of back-scattered radiation is detrimental to the image, no lead is placed behind the film. A thickness of 0.040 inch is used in front of the film for the best results. Thicknesses of from 0.010 to 0.020 inch will result in about 50 per cent more density for a given exposure, but the detail will be less clear so that it is not recommended.

The great penetration of 20-million-electron-volt X rays makes possible the study of great variations of thickness on the same radiograph. Radiographs have been taken on which differences of thickness of over six inches of steel were examined. The penetration of these X rays implies that it is difficult to detect small flaws in specimens of low density or small atomic number.

The small focal spot inherent with the betatron and not with other X-ray machines is nearly the ideal point source. The natural focal spot is 0.050 inch high and less than 0.005 inch wide. By using a special target which was developed, the height is reduced to 0.010 inch. This focal spot makes possible the enlargement of the specimen on the radiograph by increasing the specimen-to-film distance. Figure 12 shows a radiograph of a vernier caliper between two 1-inch slabs of steel with the jaws open to 0.010 inch. With a magnification of 3.3 this opening could be seen.

Figures 13 and 14 show exposure charts based on different films and screens. The exposure is given in Roentgen units *r* and on the basis that the industrial units built have given about 75 *r* per minute, the exposure times can be calculated. Figure 15 gives a comparison between different films and screens.

With the pronounced beaming of the X rays (characteristic of high energy radiation) for full utilization of the film, a good rule in the taking of radiographs is to have the target to film distance at least five times the major dimension of the film.

To show the latitude and detail of 20-million-electron-volt radiographs, Figure 16 is a radiograph of a section of a model T Ford engine. Figure 17 is a radiograph of a steel forging which showed defects that could not be determined otherwise except by very long exposures or machining and testing.

The betatron has increased to at least

Figure 17. Section of radiograph of steel forging revealing a flaw

# Application and Performance of Electronic Exciters for Large A-C Generators

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**Synopsis:** Power rectifiers have proved themselves as efficient and reliable converters of a-c to d-c power for many industrial applications. They also have been used to a limited extent as exciters for synchronous motors and condensers. This paper discusses the requirements of rectifiers when used to excite large a-c generators and presents the results of tests made to determine performance under various operating conditions. The results cover preliminary tests that were made on a laboratory model in addition to extensive and more complete tests on an electronic exciter now installed in the Springdale generating station of the West Penn Power Company. The electronic exciter was designed to serve eventually as the main exciter for an 81,250-kva 3,600-rpm turbine generator just installed, but it is now supplying excitation to a 47,100-kva 1,800-rpm turbine generator. Switching arrangements are provided for exciting either unit from the electronic exciter or from an existing motor-driven exciter.

SINCE the introduction of the metal-tank type of power rectifier, particularly the single-anode type,[1] the application of rectifiers in the field of power conversion has expanded to include practically every type of industry that requires d-c power.[2] Years of experience with many thousands of kilowatts of installed capacity testify to their reliability and efficient performance. With this background of usage, power rectifiers naturally have received consideration as exciters for rotating machines. A limited number have been used to excite synchronous motors, synchronous condensers, and one or two small generators. However, there has been a hesitancy in applying them as exciters for large a-c generators because of a natural reluctance to risk anything that might jeopardize the reliability or performance of a machine as important as a large a-c generator.

Rotating exciters have been used with success for many years, whereas the ability of a power rectifier to meet the exacting requirements of a power station generator has not been demonstrated by operating experience. It is the purpose of this paper, therefore, to discuss the application of electronic exciters to large a-c generators, to present the results of comprehensive tests that were made to demonstrate the performance of an electronic exciter under severe operating conditions, and to describe an actual installation.

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## Requirements

Large generators for power systems are capable of operating and are expected to operate months at a time without shutdown. They must maintain constant supply voltage under varying load conditions and must recover rapidly from disturbances caused by severe load fluctuations or system faults. The degree to which the generator meets these conditions depends in a large measure on the performance of its exciter, which must fulfill the following requirements:

1. It must be dependable and capable of operating without shutdown over long periods of time.
2. It should lend itself to ease of maintenance so that wearing parts can be maintained, tested, or replaced without shutting down the unit.
3. It must be capable of providing the required excitation during system disturbances when the generator may be called upon to supply a high reactive current output.
4. It must be capable of operating over a broad range of d-c voltage, from generator no-load to maximum output. Momentary values of field current considerably greater than full-load magnitude may be required.
5. It must respond rapidly to high excita-

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20 inches, the thickness of steel and other heavy materials which can be radiographed satisfactorily, the maximum thickness depending on the minimum flaw to be detected or the detail desired.

## Other Possible Uses

Any new X-ray machine is considered for its possible application to medical therapy. As the main development has been in producing a machine for industrial radiography, little time has been devoted to studying possible therapeutical application. However, one paper[10] has been published demonstrating the advantages of 20-million-electron-volt X rays and theory indicates that if the electron beam can be brought out of the donut, it would be more useful than the X rays. Both the 20-million-electron-volt X rays and electrons may be powerful weapons for the therapy of deep seated cancer.

From present indication, higher energy betatrons apparently would have no advantages in industrial radiography and their main use would probably be in connection with nuclear research. At the present time, Doctor Kerst is planning the construction of a betatron capable of producing at least 250-million-electron-volt X rays. Such a machine would enable physicists to produce radiation of cosmic ray energies in the laboratory.

## References

1. United States patent 1,645,304, J. Slepian. October 11, 1927.
2. R. Widoroe, *Archiv für Elektrotechnik*, volume 21, 1928, page 387.
3. E. T. S. Walton, *Proceedings* of the Cambridge Philosophical Society, volume 25, 1929, page 469.
4. United States patent 2,103,363, M. Steenbeck. December 28, 1937.
5. Electron Orbits in Induction Accelerator. D. W. Kerst, R. Serber. *Physical Review*, volume 60, July 1, 1941, pages 53-8.
6. Acceleration of Electrons by Magnetic Induction. D. W. Kerst. *Physical Review*, volume 58, 1940, page 841.
7. D. W. Kerst. *Physical Review*, volume 59, 1941, page 110.
8. Acceleration of Electrons by Magnetic Induction. D. W. Kerst. *Physical Review*, volume 60, July 1, 1941, pages 47-53.
9. 20 Mev Betatron or Induction Accelerator. D. W. Kerst. *Review of Scientific Instruments*, volume 13, 1942, pages 387-94.
10. Experimental Depth Dose for 5, 10, 15 and 20-Million-Volt X-Rays. H. W. Koch, D. W. Kerst, P. Morrison. *Radiology*, volume 40, February 1943, pages 120-6.

tion requirements, particularly where system stability is to be reckoned with.

6. It must be simple in structure and operation so that it does not complicate the over-all operation of the generating unit.

7. The cost, if higher, must be justified by advantages over other available methods of excitation.

## Application Problems

An electronic exciter consists essentially of a power rectifier fed from an a-c source of power and provided with the necessary control, protective, and regulating equipment. The co-ordination of these component parts presents certain problems which must be dealt with in meeting the excitation requirements of large a-c generators.

### A-C Power Supply

The rectifier may be self-excited, that is, its source of a-c power taken from the terminals of the a-c generator to which it is supplying excitation, or it may be excited separately, with its a-c power supplied from a separate source. Self-excitation makes possible unit operation with no dependence on a separate source of power for excitation. At the same time, it requires no rotating machine. However, it differs from a direct-connected rotating exciter in performance in that its output is affected by voltage dips at the generator caused by disturbances on the a-c system. The d-c ceiling voltage of the electronic exciter would decrease in proportion to the a-c voltage at a time when overexcitation is actually required by the generator. This may be compensated for in two ways. One way is to provide the rectifier with an abnormally high d-c ceiling voltage with full a-c voltage applied so that when the a-c voltage drops, the necessary d-c ceiling voltage still is obtainable. During normal operation, the d-c voltage would be reduced to normal by firing delay in the rectifier. It means a rectifier transformer somewhat larger than normal and a higher angle of firing delay during normal operation of the rectifier.

The second way to compensate for drops in a-c voltage is to provide series compensators to maintain a-c voltage on the rectifier transformer during momentary system disturbances. The primary of each of the compensators would be connected in series with one phase of the generator armature. The secondaries would be connected in series with the leads to the rectifier transformer so as to boost the a-c voltage supplied to the rectifier transformer in proportion to the reactive current fed from the generator. Either method of compensation is practical.

Separate excitation of the electronic exciter requires a reliable source of a-c power such as a separate station auxiliary generator or an auxiliary generator mechanically connected to the shaft of the main generator.

If used to supply power to the electronic exciter only, the shaft generator could be designed to feed the rectifier directly without an interposing rectifier transformer. This scheme would be comparable to a direct-connected exciter from the standpoint of being independent of system disturbances.

If the electronic exciter is self-excited, a means of supplying partial excitation during the starting-up period must be provided to get the machine up to voltage. Tests have shown that a d-c voltage of approximately 15 per cent of rated field voltage at full load applied to the field of the main generator, will start firing of the rectifier and cause it to build up voltage. This primer d-c voltage may be supplied from a small motor-generator set or from a battery connected to the generator field in parallel with the rectifier during the starting period. The motor-generator set or battery may be switched off automatically when the rectifier starts firing, by means of a reverse-current d-c relay set to detect feedback into the motor-generator set or battery.

### Co-ordination of Protective Devices

The usual complement of rectifier protective devices should be included with an electronic exciter to protect against arc-back, misfiring, loss of cooling water, and so forth. Anode circuit breakers should be provided to clear an arc back on one or two phases without interrupting the d-c output of the rectifier and also to permit isolating one or more of the anodes for maintenance without interfering with the operation of the others. Three 2-pole anode breakers, one for each pair of diametrically opposite phases of a 6-phase rectifier, normally would fulfill these requirements. The cathode breaker should not have overload protection.

The rectifier transformer normally would be connected to its a-c power source through a circuit breaker or through fuses to protect against an internal short circuit. Whichever device is used must be selected so that it will not operate on heavy exciter overloads or clear ahead of the anode breakers on arc-back.

### Regulation

The output voltage of an ignitron can be varied over a broad range by controlling the point on the a-c voltage wave at which firing occurs. This control can be

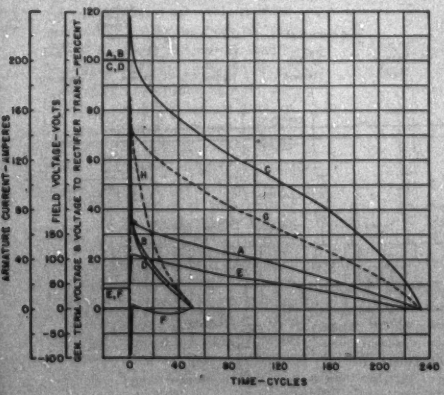



**Figure 1. Three-phase fault applied on 100-kva generator through 12 per cent external reactance with generator self-excited**

*A, B*—Terminal voltage, with and without compensator
*C, D*—Voltage to the rectifier transformer, with and without compensator
*E, F*—Field voltage, with and without compensator
*G, H*—Armature current, with and without compensator

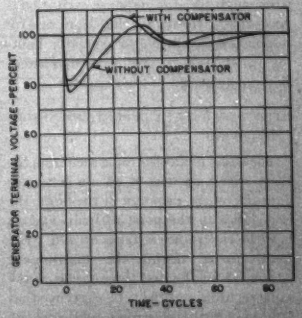



**Figure 2. Application of 100 per cent reactive load on 100-kva generator, self-excited, with and without compensator**

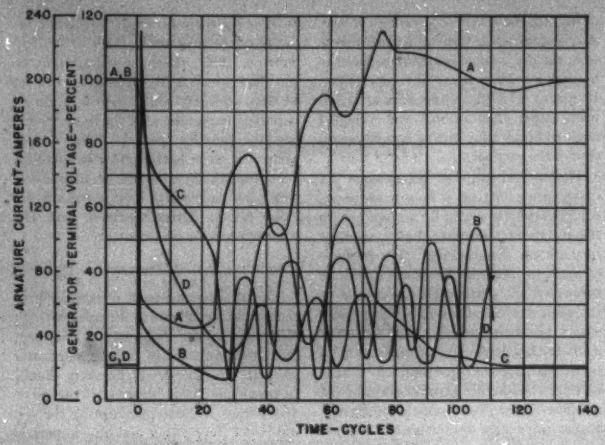



**Figure 3. Three-phase fault applied one-third of electrical distance from 100-kva generator to motor, with generator supplying 40 kw at unity power factor through 22.7 reactance between generator and motor**

*A, B*—Terminal voltage, with and without compensator

*C, D*—Armature current, with and without compensator

made broad enough to cover the full operating range of the generator without the necessity of a generator field rheostat. It can be accomplished automatically with a voltage regulator responsive to the terminal voltage of the a-c generator. Since the regulator controls only the firing circuit, it can be a low-energy device. No large rheostats or resistors are necessary.

The ability of an electronic exciter to build up to its ceiling voltage practically instantaneously makes it well suited where high speed of response excitation is necessary. However, this high rate of response is conducive to regulator hunting, which must be given particular attention in the design of the regulator.

### Effect on Fault Current and System Relaying

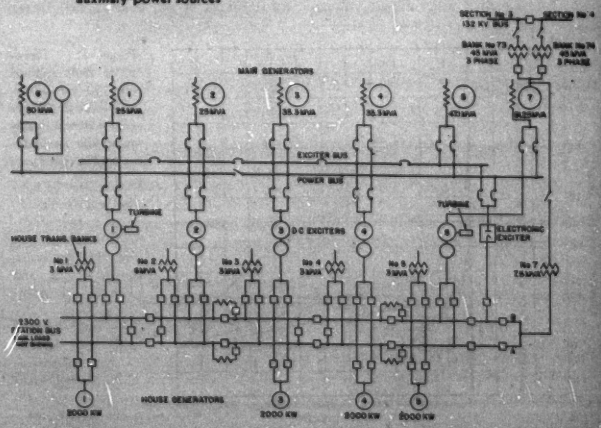
The effect of an electronic exciter on the short-circuit current of an a-c generator depends on the duration of the fault, the impedance to the point of fault, and on how the electronic exciter is excited. The fault current during the subtransient period, about the first three cycles, is the same regardless of the type of exciter that is used. If the electronic exciter is excited separately, the transient fault current and the sustained current are the same as with a rotating exciter for operation without a voltage regulator. For operation with a voltage regulator, the transient current is somewhat higher with the electronic exciter on account of its faster response. The sustained currents would be proportional to the ceiling voltages of the two exciters.

A self-excited electronic exciter with a series compensator designed to maintain a-c voltage on the rectifier during the transient period would result in about the same transient current as a separately excited electronic exciter with or without regulator operation. However, the sustained current would be proportional to the generator terminal voltage and would drop to zero if the fault were close by so that the terminal voltage dropped too low to sustain firing of the rectifier.

A self-excited electronic exciter without a series compensator and without regulator operation would cause the fault current to drop rapidly to zero if the fault impedance were low. With regulator operation and with the exciter provided with a high ceiling voltage to compensate for drop in a-c voltage, the transient current would be essentially the same as with a separately excited electronic exciter or a rotating exciter. The sustained current still would collapse to zero if the fault impedance were low.

From the above, it can be reasoned that an electronic exciter would have little or no effect on modern high-speed relays that operate in the first few cycles following a fault. The decay of fault current for low impedance faults of long duration with a self-excited electronic exciter should be taken into consideration in its effect on relay operation. It is, in general, desirable to boost or at least maintain excitation during a system fault to prevent generator instability and to hasten recovery to normal voltage after the fault is cleared. However, prolonged high excitation is undesirable where the fault is of low impedance and in a location that cannot be cleared, such as an unprotected bus. A self-excited electronic exciter would cause the fault current to collapse following the transient period and thereby make the generator self-protecting. If desired, the generator voltage could be restored after the fault was cleared by automatically applying the primer voltage to the field to start firing of the rectifier.

**Figure 4. West Penn Power Company's Springdale Power Station exciter system and auxiliary power sources**



## Tests on Laboratory Model

A laboratory model of an electronic exciter was built and tested in order to obtain fundamental data which would be a guide in the basic design of a large exciter and also to determine the effectiveness of a series compensator. This exciter consisted essentially of a rectifier transformer, six thyratron tubes, a grid transformer, and a direct-acting voltage regulator. It supplied excitation to a 100-kva 1,150-volt 1,200-rpm 3-phase synchronous generator. An auxiliary transformer was provided to transform the generator voltage to 230 volts for the rectifier transformer, the grid transformer, and the d-c grid bias circuit. The voltage regulator was used to regulate the generator terminal voltage by controlling the d-c grid bias voltage and consequently the firing of the thyratron tubes. This method of voltage control is the same as that used on the large electronic exciter discussed later.

Series compensators were provided, each consisting of three current transformers connected in series per phase with a reactor across the three secondary windings. The primaries of the compensators were connected in series with the generator armature leads; the secondaries were connected in series with the leads to the auxiliary transformer. The compensators were connected to boost the voltage to the auxiliary transformer with lagging reactive current flow from the generator. They were designed to give 100 per cent voltage compensation with 200 amperes in the primary.

### Description of Tests

The tests consisted essentially of load changes, application of faults, steady state and transient stability, transfer of excitation, and build-up of generator terminal voltage. All references to "per cent applied load" mean that the load is zero power factor lagging and is expressed as a percentage of full-load kilovolt-ampere rating of the generator. A total of 28 tests was run with oscillograms taken for each test. The generator field current and voltage, armature current, terminal voltage, the voltage to the rectifier transformer, and the d-c grid bias voltage were recorded. Reactive loads ranging from 25 to 200 per cent were applied and dropped. Three-phase and line-to-line faults were applied through approximately 12 per cent reactance on a 100-kva base. Steady-state stability tests were run with the generator connected directly to a synchronous motor load. For transient stability tests, the generator and motor were connected together through 22.7 per cent reactance on a 100-kva base, and 3-phase and line-to-line faults were applied for about one-half second at a point one-third of the electrical distance between the generator and the load. The generator was carrying 40 kw at unity power factor. All of the tests were made with and without the compensator.

### Test Results

Meter readings recorded under steady-state conditions show that the compensator boosted the voltage to the rectifier. With no compensator, the voltage to the rectifier transformer was constant for a change in generator load (80 per cent power factor) from zero to 100 per cent; with the compensator in, this voltage was about 87 per cent at no load because of the drop through the compensator. However, with an increase in load, it increased because of the boost from the compensator. At approximately 75 per cent load on the generator, it was 100 per cent and at full load was 106 per cent. At no load the angle of firing delay without the compensator was higher than with the compensator because more voltage was available to the rectifier transformer; at full load the angle of delay without the compensator was lower than with the compensator because less voltage was available to the rectifier transformer. In other words, for a change from no load to full load at a given power factor, the compensator has a regulating effect on the generator voltage with the angle of delay tending to remain more nearly constant than without the compensator.

With the generator self-excited, severe faults of long duration caused the terminal voltage and consequently the excitation to decay to zero. The faults were intentionally not cleared until after the terminal voltage had decayed to zero. As shown in Figure 1, the compensator maintains the terminal voltage approximately five times as long as without it. The compensator boosted the voltage to the rectifier transformer to approximately 113 per cent for a 3-phase fault. With an initial current of 150 amperes at two cycles, the voltage to the rectifier was boosted 77 per cent. This is equivalent to a 103-per-cent boost at 200 amperes. The decay of the armature current during the subtransient period is the same with or without the compensator. From three cycles on, the decay is much more rapid without the compensator.

Figure 2 shows terminal voltage versus time for the application of 100 per cent reactive load with and without the compensator. With the compensator the maximum voltage drop is decreased 4.5 per cent, and the generator terminal voltage is returned to 100 per cent on the first.

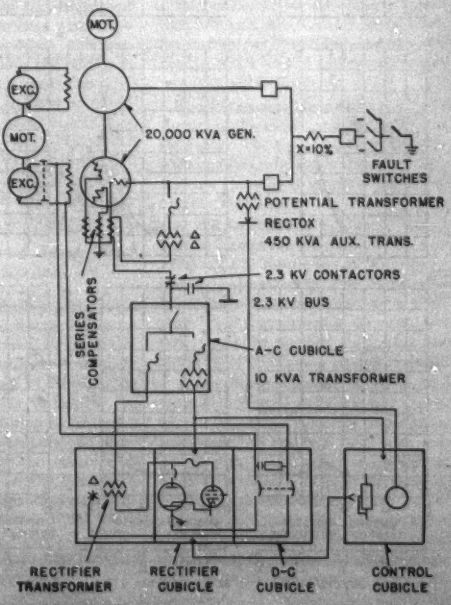



Figure 5. Schematic diagram of electronic exciter test setup in one of the a-c high-power laboratories

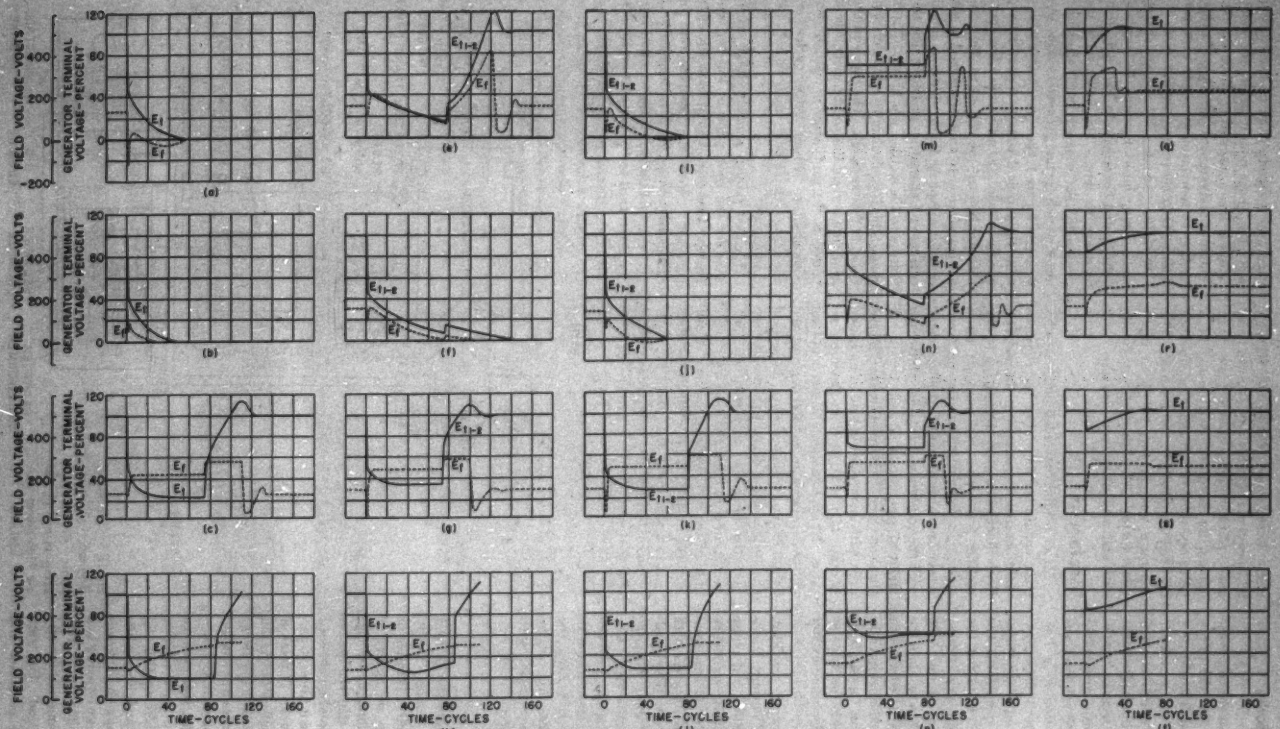



**Figure 6. Curves of terminal and field voltage for application of faults through approximately ten per cent external reactance and load changes on 20,000-kva generator**

a, b, c, d—Three-phase faults for conditions 1, 2, 3, and 5, respectively
e, f, g, h—Line-to-line faults on phases 1 and 2 for conditions 1, 2, 3, and 5, respectively
i, j, k, l—Double line-to-ground faults on phases 1 and 2 for conditions 1, 2, 3, and 5, respectively
m, n, o, p—Single line-to-ground faults on phase 1 for conditions 1, 2, 3, and 5, respectively
q, r, s, t—Application of 60 per cent reactive load for conditions 1, 2, 3, and 5, respectively

overshoot, ten cycles sooner than without the compensator. The terminal voltage ultimately is returned to normal in about 65 cycles with the compensator, compared with 80 cycles without the compensator.

A comparison of the transient stability characteristics of the generator with and without a series compensator is shown in Figure 3. Without the compensator the generator pulled out of step and did not regain synchronism. However, with the compensator, synchronism was not lost and the terminal voltage returned to a constant value in 111 cycles after the fault was cleared.

## Application to West Penn Power Company System

The Springdale generating station includes five 1,800-rpm turbine generators excited from motor and dual-driven exciters with switching for exciting any generator from any exciter through excitation busses. There is one 3,600-rpm 50,000-kva high pressure unit with a direct-connected exciter.

The new number 7 unit, rated 81,250 kva 3,600 rpm, is practically a separate station electrically, with no paralleling of circuits other than at 132 kv. Only a few of the auxiliaries for this unit are supplied from the existing 2,300-volt auxiliary bus. A shutdown would therefore be very costly.

In order to eliminate shutdown because of the possibility of exciter trouble which might require mechanical disconnection from the shaft of the main unit, a separate exciter source was decided upon, and an electronic type was selected. Initially, this exciter supplies excitation to one of the existing generators. The number 5 dual-driven exciter, supplied from either one of the existing 2,300-volt station auxiliary busses, supplies excitation to the number 7 unit. A pilot exciter was added to the shaft of this dual set. This was considered a reliable source of excitation because there has been no outage to these busses or to the dual set over a period of years. After sufficient operating experience is obtained with the electronic exciter on one of the older units, it will serve as the main exciter for the number 7 unit for which it originally was designed. Any one of the older generators can be excited from the electronic exciter or any of the station exciters as shown in Figure 4.

When the electronic exciter is used to excite the number 7 unit, it operates essentially self-excited, subject to drop in the terminal voltage of the generator. A 3-phase fault at the high-voltage terminals of the step-up transformers with the 132-kv bus tie breaker closed would cause the generator terminal voltage to drop instantly to approximately 50 per cent. Faults at other locations on the high-voltage system would result in less voltage drop.

The rectifier transformer was designed to give approximately 400 volts d-c ceiling with full a-c voltage applied, so as to assure excitation during fault periods. It also is provided with an extension to the high-voltage winding to give a ceiling d-c voltage of approximately 300 volts, which would correspond to a normal design to be operated either separately excited without a compensator or self-excited with a compensator. Both schemes of compensation were used in making the laboratory tests to be described later. The series compensators used in the tests proved inadequate for the compensation desired, so the exciter was installed to operate on the high-voltage taps without series compensators. Space is available for future installation of compensation and their connections if proved desirable.

**Table I. Characteristics of Generators**

| | Laboratory Test Generator | Springdale Station No. 7 Generator |
|---|---|---|
| Generator rating | 30,000 kva | 81,250 kva |
| Normal rated voltage | 6,600 volts | 11,500 volts |
| Synchronous reactance, per unit | 0.853 | 1.20 |
| Transient reactance, $X_{d'}$ sat. per unit | 0.10 | 0.117 |
| Negative-sequence reactance, $X_2$ per unit | 0.10 | 0.073 |
| Zero-sequence reactance, $X_0$ per unit | 0.025 | 0.087 |
| Open-circuit transient time constant $T'_{do}$ | 3.2 sec | 7.55 sec |
| Field resistance at 75° C. | 0.145 ohm | 0.234 ohm |
| No load field current | 830 amp | 400 amp |
| Full load 80% power factor field current | 1,340 amp | 800 amp |

## Laboratory Tests on West Penn Power Company Exciter

Laboratory tests on the model proved the feasibility of an electronic exciter for excitation of a synchronous generator. They also showed that a series compensator could be designed which would be effective in maintaining voltage to the rectifier transformer during the transient period under fault conditions. In order to obtain complete performance data on the electronic exciter for the West Penn Power Company for operating conditions which might occur in service but which could not readily be staged on the actual installation, extensive tests were made on this exciter at the factory.

**Table II. Estimated Maximum Fault Clearing Time to Permit Recovery of Generator Voltage**

| Type of Fault | Time in Cycles Condition 1 | Condition 2 | Condition 4 |
|---|---|---|---|
| Three-phase | .32 | .27 | .28 |
| Line-to-line | .78* | .56 | .59 |
| Double line-to-ground | .47 | .34 | .38 |
| Single line-to-ground | .75** | .75* | .74* |
| Line-to-line fault with one anode breaker open | .78* | .49 | .57 |

*Fault was cleared at this time.

**Maximum fault clearing time is infinite.

The tests were made in one of the a-c high-power laboratories. A schematic diagram of the electronic exciter and the associated test apparatus is shown in Figure 5. The laboratory consists of a 3,300-horsepower motor driving two 20,000-kva generators which are synchronized mechanically so that their respective voltages are in phase. A motor-driven dual exciter set is provided to furnish excitation to each generator. Switching arrangements are such that the two generators can be paralleled or one can be used alone. Facilities are available for applying any type of fault through an external reactance from zero to five ohms. Reactive load can be applied on either generator by paralleling it with the other underexcited.

The electronic exciter consists essentially of an a-c cubicle, an air-cooled rectifier transformer, a rectifier cubicle, a d-c cubicle, and a control cubicle, all shown schematically in Figure 5.

The voltage regulator and firing control circuits of this exciter and the model are the same. The thyratron tubes fire the ignitron tubes, whereas on the model they were used actually to supply power to the field circuit.

A 450-kva transformer bank transformed the generator terminal voltage to 2,300 volts to supply the rectifier transformer. Mechanically and electrically interlocked 2,300-volt contactors were provided so that power for the electronic exciter could be supplied from either the generator terminals or a separate source.

The series compensators, shown in Figure 5, were selected with the idea of boosting the a-c voltage applied to the rectifier transformer 50 per cent (625 volts per phase) with 25,000 amperes through a single-turn primary. This is the value of generator transient current that would result for a 3-phase fault on the high-voltage terminals of the transformers connected to the number 7 unit at Springdale. With the test generator connected

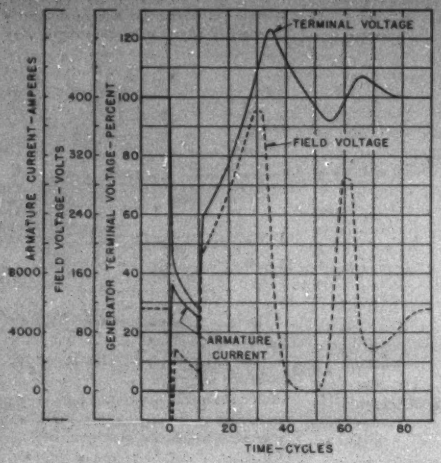



**Figure 7. Three-phase 10-cycle fault applied on 20,000-kva generator through ten per cent external reactance. Generator was self-excited and rectifier transformer was on high-voltage tap**

for 6,600 volts, line-to-line, the transient current for a 3-phase fault with 10 per cent (20,000-kva base) external reactance between the generator and fault is approximately 8,750 amperes. Therefore, one compensator was connected in the neutral leg of each phase of the generator with three loops through the primary to obtain the equivalent ampere turns of the actual installation. The generator neutral was grounded solidly to permit the application of ground faults.

The electrical characteristics of the test generator and the number 7 generator are compared in Table I. The full-load field voltage of the test generator during tests was about 15 per cent greater than the full-load field voltage on the number 7 generator at normal operating temperature. The full-load field current of the test generator is 1.67 times that of the number 7 generator. This, together with the smaller auxiliary transformer (450 kva compared with 7,500 kva), resulted in a higher d-c voltage regulation of the rectifier in the laboratory tests than in the actual installation. The shorter time constants of the test generator resulted in faster decay of voltages and currents during faults.

## Description of Tests

The tests consisted essentially of the application of all types of faults, application and dropping of reactive load, changeover from self-excitation to separate excitation, simulated arc-backs and sympathetic arc-backs, and build-up of generator terminal voltage.

The tests were made under the five following conditions of excitation:

1. The rectifier transformer was connected on the high-voltage tap (approximately 400 volts d-c, no-load ceiling) and the compensators were not connected in the circuit. The generator was self-excited, that is, the supply to the rectifier transformer was taken from the generator terminals.

2. The rectifier transformer was connected on the low-voltage tap (approximately 300 volts d-c, no-load ceiling) and the compensators were not connected in the circuit. The generator was self-excited.

3. The rectifier transformer was connected on the low-voltage tap and the compensators were not connected in the circuit. The generator was excited separately, that is, the supply to the rectifier transformer was taken from a separate a-c source.

4. The rectifier transformer was connected on the low-voltage tap and the compensators were connected. The generator was self-excited.

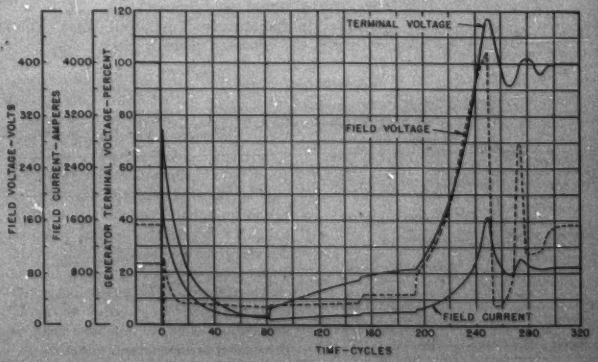
5. The rotating exciter was used to excite the generator field. A high-speed contactor short-circuited the exciter field resistance to assimilate the high-speed field-forcing contactor in a rheostatic type voltage regulator. The output ceiling voltage of the rotating exciter is 270 volts and the response ratio is 0.5.

For each of these conditions, 60 per cent reactive load was applied and dropped, and a 3-phase, a line-to-line, a double line-to-ground, and a single line-to-ground fault was applied. To assimilate faults on the 132-kv bus on the actual installation, all faults were applied through ten per cent external reactance on a 20,000-kva base. Under this condition the initial generator terminal voltage drop was approximately 50 per cent. With the exception of condition 5, a line-to-line fault was applied with each of the anode breakers open. This assimilates a line-to-ground fault on the 132-kv West Penn Power Company system during operation with one rectifier cubicle (two ignitron tubes) out of service for maintenance. The duration of the faults was approximately 1.25 seconds. This was longer than would be expected in normal operation but was desirable in order to determine the performance of the electronic exciter for disturbances of long duration.

For electronic exciter tests on which oscillograms were taken, 24 quantities were recorded simultaneously on three 9-element oscillographs as follows:

3—generator line-to-line terminal voltages
3—generator line currents
1—generator field voltage
1—generator field current
1—thyratron tube d-c grid bias voltage

**Figure 8. Severe long-duration fault on 20,000-kva generator with primer voltage applied to return terminal voltage to normal after fault was cleared**



3—line-to-line voltage applied to the rectifier transformer
6—anode to cathode voltages
6—anode currents

Only the first eight quantities were recorded for tests involving the rotating exciter.

### Test Results

Figure 6 shows curves plotted from oscillograms of generator terminal voltage and field voltage versus time for a 3-phase fault, a line-to-line fault, a double line-to-ground fault, a single line-to-ground fault, and application of 60 per cent reactive load. The results of the tests made under conditions 1, 2, 3, and 5 are shown. Condition 4 is not included because the results were about the same with the compensators as without them. This was primarily because of the high-voltage regulation in the a-c supply circuit to the rectifier, which resulted from the high field current requirements of the test generator. In those cases where the field voltage becomes a negative value, the induced voltage in the field resulting from fault current in the armature is higher than the rectifier output voltage.

Faults of short duration similar to those normally experienced with modern high-speed relays and breakers were also applied. Curves plotted from an oscillogram of a 3-phase 10-cycle fault are shown in Figure 7. The rectifier transformer was connected on the high-voltage tap and the generator was self-excited.

The tests showed that with the generator self-excited and the rectifier transformer on the high-voltage tap, a 3-phase fault must be cleared in approximately 30 cycles to permit the generator terminal voltage to return to normal. The maximum fault clearing times to permit recovery of generator voltage for other types of faults were estimated from the oscillogram and are shown in Table II.

Figure 8 shows how the generator terminal voltage was returned to normal following a long duration 3-phase fault which caused the rectifier to stop firing because of the decay of terminal voltage to zero. About 40 cycles after application of the fault, a 32-volt d-c source was automatically connected to the generator field. This is the lowest voltage which will cause the ignitron tubes to fire and consequently build up the generator voltage. The fault was cleared in 82 cycles and the ignitron tubes started to fire at 152 cycles. At 194 cycles the rectifier voltage was high enough to cause reverse current to flow into the 32-volt d-c supply, which was tripped off by means of a reverse current relay. From 194 cycles to 300 cycles, the curves show the action of the voltage regulator and the build-up of the terminal voltage, which becomes a constant value of 100 per cent at 300 cycles.

During the tests, one arc-back and one sympathetic arc-back occurred which caused the associated anode breaker to open. Both occurred with cold tubes and with the rectifier supplying no load excitation to the generator with operation of the tubes at a high firing delay. Such conditions are known to increase the probability of arc-back and sympathetic arc-back.[3] No oscillograms were obtained because they occurred at a time when no records were being made. Arc-backs were simulated by short-circuiting a rectifier tube. The tests were run with the rectifier transformer separately excited with no load on the rectifier and with the tubes firing at zero degrees delay. Under these conditions the arc-back currents were maximum. Sympathetic arc-backs were simulated by short-circuiting two ignitron tubes connected to adjacent phases of the rectifier transformer. Power to the rectifier was supplied from the generator terminals and the voltage regulator was in service. The anode breakers opened in $2^1/_2$ cycles and the rectifier functioned with four tubes out of service. As shown in an oscillogram of one of the tests, Figure 9, there was no disturbance to the generator terminal voltage.

A total of 43 fault, 7 load change, 14 arc-back, 22 sympathetic arc-back, 1 transfer of excitation, and 3 generator voltage build-up tests was recorded on oscillograms. In addition, a number of tests were made without taking oscillographic records. It is believed that the results of these tests provide valuable information that could not be obtained in actual service even over many years.

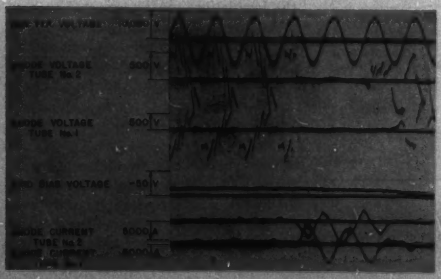



Figure 9. Oscillogram of sympathetic arc-back on ignitron tubes 1 and 2, simulated by short-circuiting each tube simultaneously

## Conclusions

1. Extensive laboratory tests based on pessimistic conditions that are unlikely to be matched in service have demonstrated that an electronic exciter can be depended on as a reliable source of excitation for large a-c generators.

2. The type of a-c power supply to the rectifier best suited to the application is dependent on the particular conditions.

3. If self-excited, the electronic exciter should have either a high ceiling voltage or should be provided with series compensators to compensate for drop in a-c voltage during system disturbances. Either method is practical.

4. An electronic exciter may be installed at any desired location in the generating station, it is easy to maintain, it has an inherent high speed of response, and it is adapted easily to generator voltage regulation. Its cost is higher than that of a rotating machine.

5. Modern high-speed relaying would not be affected by using electronic exciters instead of the rotating type. Relays with long time settings, in excess of one second, might be affected if the electronic exciter operates self-excited because of faster decay of short-circuit current.

6. An a-c generator self-excited with an electronic exciter can be operated as an independent unit in an isolated station. A primer excitation for starting can be obtained from a battery or small motor-generator set.

7. The decay of short-circuit current for long-duration low-impedance faults with a self-excited electronic exciter would prevent excessive fault damage. If desired, generator voltage can be restored by automatically applying a primer voltage to the field to start firing of the rectifier.

## References

1. A New Method for Initiating the Cathode of an Arc. J. Slepian, L. R. Ludwig. AIEE Transactions, volume 52, 1933, June section, page 693–8.

2. Ignitron Rectifiers in Industry. J. H. Cox, G. F. Jones. AIEE Transactions, volume 61, 1942, October section, pages 713–18.

3. Arc-Backs in Rectifier Circuits Artificial Arc-Back Tests. R. D. Evans, A. J. Maslin. AIEE Transactions, volume 64, 1945, June section, page 303–11.

# Peak Voltages Induced by Accelerated Flux Reversal in Reactor Cores Operating Above Saturation Density

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**Synopsis:** The existence of peak voltages in the windings of many sorts of series transformers and reactors, when abnormal conditions force the flux density above saturation, has been understood in a qualitative manner for many years. This paper will derive means for calculating these voltages for the various combinations of magnetizing force and rate of variation. The close agreement between test and calculation over a wide range of magnetizing forces indicates the accuracy and general applicability of the method.

THE magnetic flux in a-c apparatus usually varies nearly sinusoidally over a range of flux densities well below the saturation value. However, in certain types of apparatus, notably series apparatus, abnormal conditions will produce magnetizing forces as high as hundreds of times normal, and the flux density will not only reach saturation, but the flux variation will no longer be sinusoidal. The variation of the flux through zero is usually accelerated and induces relatively enormous peak voltages.

Examples of such apparatus are:

1. Current transformers under overcurrent, high burden (or a combination), or open circuit.
2. Preventive autotransformers when a tap change coincides with a line fault.
3. Series transformers for street lighting when a lamp burns out.

The existence of these voltages is well known, but only very approximate methods,[1] limited in application, have been derived for calculation of their values. With recent increases in capacities of systems, the possible voltages are higher and more dangerous than ever. One-ampere secondary current transformers are being used more frequently, and their voltages are five times as high as standard. Hence it has become more necessary to have more generally applicable, more exact, means of calculation of voltage.

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## Peak Voltage Phenomenon and Methods of Analysis

The conventional description of the phenomenon is illustrated in Figure 1A. Starting at point *A* on the current wave, the reactor is saturated, and as the current decreases, the flux changes very little and the voltage is nearly zero. As the current decreases to the saturation value near *B*, the flux starts to decrease, and the flux change is accelerated through current zero at *C*, inducing a high-voltage peak.

The high-voltage peak, induced by the high inductance of the saturating reactor near current zero, resists the change in the primary current, the high inductance tending to maintain the current and thus to make the peak voltage itself less than it would be otherwise if the current wave maintained its sinusoidal shape. Analysis of the circuit to determine the effect of the peak voltage on the wave shape of the current and the determination of the resulting peak voltage is the first part of the problem.

The high rate of flux change induces eddy currents in the lamination which are very effective toward maintaining the flux, delaying its change. Analysis of these eddy currents is the second part of the problem.

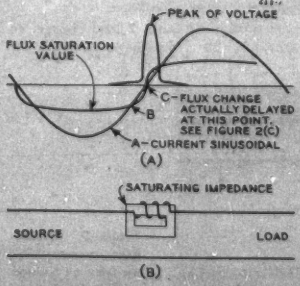


**Figure 1. Illustration of the problem with conventional description of mode of flux variation**

Compare with Figure 2 and Figure 11

Two methods of analysis of the whole problem have been developed. Method *A* gives a satisfactory solution of the first part of the problem (variation of voltages and currents in the circuit) based on an assumption as to the solution of the second part. Method *B* gives the solution of the second part of the problem (eddy currents and their effect on the flux distribution and voltage) based on an assumption as to the solution of the first part. The use of two methods can be justified by the fact that although neither method gives exactly the correct result, they do give the approximate upper and lower limits of possible peak voltage.

The advantage of method *A*, analysis by the assumption of uniform flux density in the lamination, is that it permits representing the actual reactor by an equivalent perfect reactor in parallel with a resistor, according to Figure 2. This enables the mathematical analysis of the circuit which will be given later.

The classic analysis of eddy currents is based on the assumption of uniform flux density. The loss then is proportional to the square of the rate of flux change or, instantaneously, to the square of the voltage induced in the reactor. Clearly, a resistor shunted across the reactor has a loss varying in the same way, and a resistor *R* in parallel with a perfect reactor *L*, as in Figure 2, will represent the actual reactor.

By method *B* determination of flux distribution in the lamination, the variation of flux is analyzed on the basis that a sine wave of current is maintained through the reactor, and the effect of the eddy currents in forcing the flux to redistribute itself toward the surface of the lamination is determined.

Method *B*, which takes account of the effect of the eddy currents in forcing the flux change to occur first at the surface of the lamination, can be expected to give lower voltages. The analyses to be given show that it gives a voltage about half as great, and the tests show that the actual values are between the two.

## Mathematical Analysis

The equivalent reactor (or primary of the series transformer) in method *A* (see Figure 2B) is not a constant quantity; as the flux in the core increases toward saturation, the permeability and effective inductance decrease to a value only a small

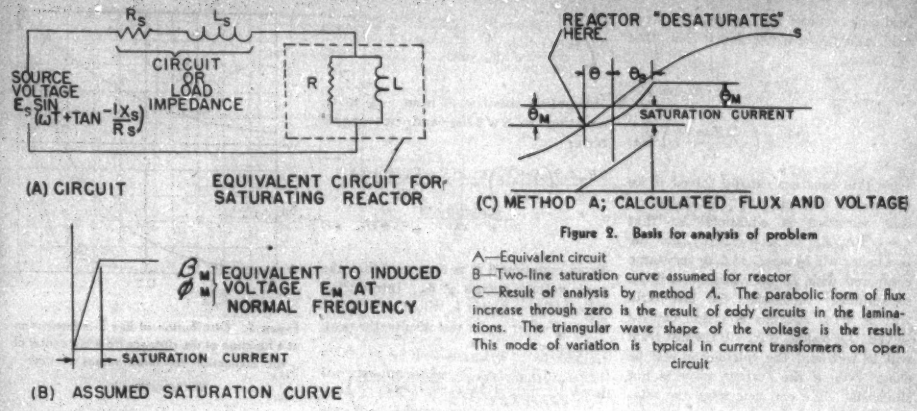


**Figure 2. Basis for analysis of problem**

A—Equivalent circuit
B—Two-line saturation curve assumed for reactor
C—Result of analysis by method *A*. The parabolic form of flux increase through zero is the result of eddy circuits in the laminations. The triangular wave shape of the voltage is the result. This mode of variation is typical in current transformers on open circuit

fraction of the initial value, and in a complicated manner that cannot be represented by any simple formula. Therefore some simplifying assumptions will have to be made. An obvious device which has been used in similar problems is to assume that the saturation curve is composed of two straight lines, as shown in Figure 2B. The voltage induced by $B_m$ at normal frequency will be $E_m$; the method of determining $E_m$ from the *AC* saturation curve of the reactor is given in Appendix I.

The hysteresis loop, by this assumption, is assumed to have zero area. As it will appear later that the permeability of the iron is not too important in determining the peak voltage, the variation of permeability during the hysteresis loop reasonably may be neglected.

### Method *A*

Method *A*, as has been shown, is based on analysis of the circuit of Figure 2A. For this circuit we may write the equations

$$\sqrt{2}E_s \sin\left(\omega t + \tan^{-1}\frac{X_s}{R_s}\right) - i_s R_s - L_s\frac{di_s}{dt} - L\frac{di_L}{dt} = 0 \quad (1)$$

The reason for writing in $\tan^{-1} X_s/R_s$ is that the resulting equations are simplified. The current $i_n$, which would flow in the circuit if the series reactor were not present, is $i_n = (E_s/Z_s)\sin\omega t$. Time = 0 is thus when the current would be zero if the reactor were not in the circuit.

$$L\frac{di_L}{dt} = i_R R = e \quad (2)$$

$$i_s = i_L + i_R \quad (3)$$

A further limitation, inherent in the nature of the reactor, is that $L = 0$ if $i_L$ exceeds the saturation value. If we suppose the current to exceed this value initially (at point *A*, Figure 2C) and to be decreasing sinusoidally toward zero, it all will be flowing in the *L* branch, none in the *R* branch, of the equivalent reactor because $L = 0$ while the current exceeds the saturation value. At some time $-t_\theta$ or time angle $-\theta_\theta$, the current decreases to the value at which the reactor "desaturates" and suddenly regains its inductance *L*. The flux must remain momentarily at the same value, so that the current in the reactor ($i_L$) must have an initial value at time angle $-\theta_\theta$ equal to the saturation value, with zero current in the resistor *R* and zero voltage across the reactor. The value of $-\theta_\theta$ is derived in Appendix II.

As the flux in the reactor reverses, the current in the reactor branch *L* finally reaches the saturation value again at some time $t_s$ (angle $\theta_s$), at which time the inductance *L* becomes zero, all the current transfers to the *L* branch, and the circuit carries on until the next half-cycle.

Equations 1, 2, and 3 are obviously very difficult to solve for $i_L$ or $i_R$.* Some assumptions or simplifications must be made. The solution can be worked out by either of two assumptions.

*Solution by Assumption Number 1.* Neglect $R_s\{[(\sqrt{2}E_s\omega t)/Z_s] - i_s\}$. The demonstration that the solution is valid for low-power-factor circuits follows.

If we write equation 1 in the form

$$L_s\frac{di_s}{dt} + L\frac{di_L}{dt} = \sqrt{2}E_s \sin \times \left(\omega t + \tan^{-1}\frac{X_s}{R_s}\right) - R_s i_s$$

* This equation can be solved for $s$ because the differential equation

$$\frac{d^2i_L}{dt^2} + \left(\frac{R_s}{L_s} + \frac{R}{L_s} + \frac{R}{L}\right)\frac{di_L}{dt} + \frac{RR_s}{LL_s} i_L = \frac{Rs_s}{LL_s}$$

can be derived from it ($s_s$ = source voltage). The solution is of the form $i_L = K_1 \epsilon^{\lambda_1 t} + K_2 \epsilon^{\lambda_2 t} +$ steady state current. The initial and final conditions are the same. $\lambda_1$ and $\lambda_2$ come out to be rather complicated functions of $R$, $R_s$, $X$, $X_s$, while $K_1$ and $K_2$ are still more complicated functions of $\lambda_1$, $\lambda_2$ and the other variables. The final solution is difficult to work with, and as the more simple solutions give results sufficiently accurate for the purpose (especially in light of the fact that the basic assumption of a constant $R$ introduces some error), only the simple solutions are given in complete form and the calculations will be based on these simple solutions. The values of $\lambda_1$, $\lambda_2$, $K_1$, and $K_2$ are given in Appendix V.

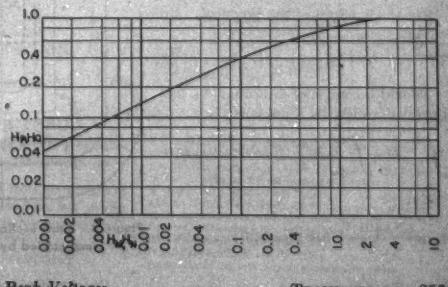


**Figure 3. Curve of $H_\theta$ as a function of $H_m$ (or $H_\epsilon$ as a function of $H_m$)**

and if we consider the current reversal to take place in such a short time that $\sin \omega t = \omega t$,

$$L_s\frac{di_s}{dt}+L\frac{di_L}{dt}=\sqrt{2}\frac{E_sX_s}{Z_s}+R_s\left(\sqrt{2}\frac{E_st\omega}{Z_s}-i_s\right) \quad (4)$$

Now this equation can be solved if we can neglect the last term. But if the current variation is sinusoidal so that $i_s=\sqrt{2}(E_s/Z_s)\sin\omega t=\sqrt{2}(E_s/Z_s)t\omega$ the last factor will be zero. If $L_s$ is very large compared with $L$, the variation will be substantially sinusoidal, the last term will be zero, and the equation can be solved. Of course, if $R_s=0$, the last term will be zero and the calculation will be exact, even if the current wave is not sinusoidal. We can determine the relative magnitude of error by solving the equation for $i_s$, and determining the relative magnitude of the $i_sR$ part of the last term which has been neglected. This will indicate the approximate amount of error. The ratio of this error to the other term $\sqrt{2}(E_sX_s/Z_s)$ will come out equal to

$$\frac{R_s}{X}\left[\frac{X}{X+X_s}\omega(t+t_d)+\left(\frac{X}{X+X_s}\right)^2\times\frac{X_s}{R}\left(1-\epsilon^{-\frac{R(X+X_s)}{XX_s}(t+td)}\right)\right]$$

Examples worked out for different circuit constants indicate that the maximum usual error will not exceed 20 per cent. Tests to be given indicate good agreement.

Then we can write for Equation 4

$$\sqrt{2}\frac{E_sX_s}{Z_s}=L_s\frac{di_s}{dt}+L\frac{di_L}{dt} \quad (4a)$$

Eliminating $i_s$ and $i_L$ by Equations 2 and 3,

$$\frac{de}{dt}+\frac{R(L+L_s)}{LL_s}e=\frac{\sqrt{2}E_sR\omega}{Z_s} \quad (5)$$

Solving this equation, using the initial condition that $e=0$ at $\omega t=-\theta_d$,

$$e=\frac{\sqrt{2}E_sXX_s}{Z_s(X+X_s)}\left(1-\epsilon^{-\frac{R(X+X_s)}{XX_s}(\theta+\theta d)}\right) \quad (6)$$

For small values of the exponent,

$$e=\frac{\sqrt{2}E_sR}{Z_s}(\theta+\theta_d) \quad (7)$$

To find the angle of saturation, $\theta_s$, use the relation that $e=N(d\phi/dt)10^{-8}$

$$\int_{-\theta_d}^{\theta_s}ed\theta=\int_{-t_d}^{t_m}\omega N\frac{d\phi}{dt}10^{-8}dt=2\omega N\phi_m10^{-8}$$

But

$$E_m=\frac{\omega N\phi_m10^{-8}}{\sqrt{2}} \quad \text{(see Figure 2B)}$$

So that

$$\int_{-\theta_d}^{\theta_s}ed\theta=2\sqrt{2}E_m \text{ volts} \quad (8)$$

Integrating equation 6 from $-\theta_d$ to $\theta_s$, equating to $2\sqrt{2}E_m$, and rearranging terms,

$$\frac{2E_mZ_sR}{E_s}\left(\frac{X+X_s}{XX_s}\right)^2=\frac{R(X+X_s)(\theta_s+\theta_d)}{XX_s}+\epsilon^{-\frac{R(X+X_s)(\theta_s+\theta d)}{XX_s}}-1=H_m \quad (9)$$

From equation 6 it is apparent that the peak voltage occurs at $\theta_s$. Introducing an experience factor $k$, which will be discussed further under test results, the peak voltage is

$$e_p=k\frac{\sqrt{2}E_sXX_s}{Z_s(X+X_s)}\left(1-\epsilon^{-\frac{R(X+X_s)(\theta_s+\theta d)}{XX_s}}\right) \quad (10)$$

Let

$$H_p=1-\epsilon^{-\frac{R(X+X_s)(\theta_s+\theta d)}{XX_s}} \quad (11)$$

Then

$$e_p=k\frac{\sqrt{2}E_sXX_s}{Z_s(X+X_s)}H_p \quad (12)$$

It can be seen from equations 9 and 11 that $H_m$ and $H_p$ are functions of the same parameter. It is then possible to plot $H_p$ directly as a function of $H_m$. This curve is shown in Figure 3. $H_m$ can be calculated from the first part of equation 9, $H_p$ read from Figure 3, and $e_p$ calculated by equation 12. If the angle $\theta_s+\theta_d$

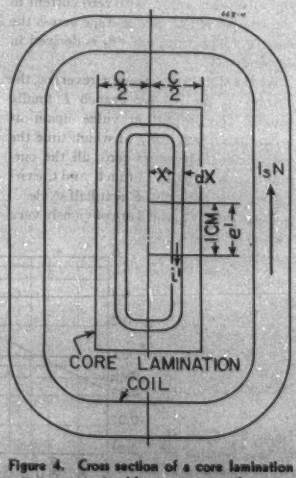


**Figure 4. Cross section of a core lamination magnetized by a primary coil**

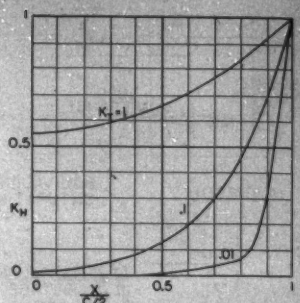


**Figure 5. Distribution of flux in a lamination as a function of the distance from the center of the lamination for three values of time**

See equation 46

is desired, it can be found from equation 11 as follows:

$$\theta_s+\theta_d=\frac{1}{k}\frac{XX_s}{R(X+X_s)}\times\log_\epsilon\frac{1}{1-H_p} \text{ radians} \quad (13)$$

Here the angle is divided by the experience factor $k$; for whatever the peak voltage is reduced by, the angle will be increased by, as is apparent from equation 8. For accurate results this angle should be less than one-half radian.

*Solution by Assumption Number 2.* Neglect $L_s[(\sqrt{2}\omega E_s/Z_s)-(di_s/dt)]$. The demonstration that the solution is valid for high-power-factor circuits follows.

We may also write equation 1 in the form

$$I_sR_s+L\frac{di_L}{dt}=\sqrt{2}E_s\sin\left(\omega t+\tan^{-1}\frac{X_s}{R_s}\right)-L_s\frac{di_s}{dt} \quad (14)$$

or, as before, letting $\sin\omega t=\omega t$

$$i_sR_s+L\frac{di_L}{dt}=\sqrt{2}\frac{E_s}{Z_s}R_s\omega t+L_s\left(\sqrt{2}\frac{E_s}{Z_s}\omega-\frac{di_s}{dt}\right) \quad (15)$$

Again it appears that the equation can be solved if we neglect the last term. Again, if $i_s=\sqrt{2}(E_s/Z_s)\omega t$ so that $di_s/dt=\sqrt{2}(E_s/Z_s)\omega$, the last factor is zero, so that this equation is also valid if the series impedance is so high as to maintain sinusoidal current. And obviously it is valid for $L_s=0$, but not for $R_s=0$, so that the solution will be valid for high-power-factor circuits.

Then we may write equation 15 with-

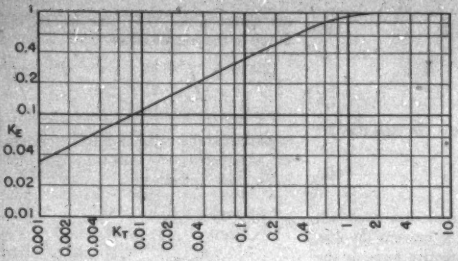


**Figure 6. Curve of $K_\epsilon$ as a function of $K_t$**
See equation 48

out the last term, and again eliminating $i_s$ and $i_L$ by use of equations 2 and 3, we get

$$\frac{de}{dt}+\frac{RR_s}{(R_s+R)L}e=\frac{\sqrt{2}E_gR_sR\omega}{Z_s(R_s+R)} \tag{16}$$

At $\omega t=-\theta_d$, $e=0$,

$$e=\frac{\sqrt{2}E_gX}{Z_s}\left(1-\epsilon^{-\frac{RR_s(\theta+\theta_d)}{(R_s+R)X}}\right) \tag{17}$$

For small values of the exponent,

$$e=\frac{\sqrt{2}E_gRR_s}{Z_s(R_s+R)}(\theta+\theta_d) \tag{18}$$

Comparing with equation 7, it is seen that the two methods result in the same voltage if $R_s$ is large compared to $R$. Integrating equation 17 from $-\theta_d$ to $\theta_1$ as in equation 8,

$$\frac{2E_mZ_sRR_s}{(R_s+R)X^2E_g}=\frac{RR_s(\theta_s+\theta_d)}{(R_s+R)X}+\epsilon^{-\frac{RR_s(\theta_s+\theta_d)}{(R_s+R)X}}-1=H_m \tag{19}$$

and

$$H_\theta=1-\epsilon^{-\frac{RR_s(\theta_s+\theta_d)}{(R_s+R)X}} \tag{20}$$

$H_m$ and $H_\theta$ are of the same form as in equations 9 and 11 but are functions of a different parameter. Introducing the experience factor $k$, equation 17 becomes

$$e_p=k\frac{\sqrt{2}E_gX}{Z_s}H_\theta \tag{21}$$

It is evident that Figure 3 also may be used to evaluate $H_m$ and $H_\theta$. Method 1 above is exact for $R_s$ equal to zero and method 2 is exact for $X_s$ equal to zero. The calculated voltages for intermediate power factors will be too low by either formula unless the series impedance is high enough to keep the source current sinusoidal. If the peak voltage is calculated by both methods, the larger of the two answers should be correct within a reasonable degree of accuracy.

From Figure 3 it is evident that the straight line relationship

$$H_p=\sqrt{2H_m}\ (\text{or } H_\theta=\sqrt{2H_m}) \tag{22}$$

is entirely adequate if $H_m$ or $H_\theta$ is less than one-tenth. That equation 22 is the exact relation for low values of the variables can be demonstrated by expanding the expressions for $H_p$ and $H_m$ from equations 11 and 9 in infinite series, retaining only the lowest-powered term in each, and then eliminating the parameter between the two equations. Substituting the value of $H_m$ from equation 9 into equation 22, and this value of $H_p$ into equation 12, gives

$$e_p=k\left(\frac{8E_gE_mR}{Z_s}\right)^{1/3} \tag{23}$$

It can be shown that this same equation holds for method 2 for a high-power-factor circuit if $R_s$ is large compared with $R$. From equations 7 or 18, it is evident that the voltage wave shape is essentially triangular.*

To get the root mean square voltage, we can write

$$\int_{-\theta_d}^{\theta_s}ed\theta=\frac{1}{2}\left[k\left(\frac{8E_gE_mR}{Z_s}\right)^{1/3}\right]\times(\theta_s+\theta_d)=2\sqrt{2}E_m \tag{24}$$

$$\theta_s+\theta_d=\frac{2}{k}\left(\frac{E_mZ_s}{E_gR}\right)^{1/3}\text{ radians} \tag{25}$$

The expression for the voltage $e$ can be rewritten as follows, where $e_p$ is the peak value as given by equation 23:

$$e=e_p\frac{\theta+\theta_d}{\theta_s+\theta_d} \tag{26}$$

To find the root mean square value of this voltage, the value of $e$ is substituted in the following formula and evaluated.

$$e_{rms}=\left(\frac{1}{\pi}\int_{-\theta_d}^{\theta_s}e^2d\theta\right)^{1/2} \tag{27}$$

$$=e_p\left(\frac{\theta_s+\theta_d}{3\pi}\right)^{1/2}\text{ volts} \tag{28}$$

The values from equations 23 and 25 can be substituted in equation 28.

$$e_{rms}=\sqrt{k}\frac{4}{\sqrt{3\pi}}\left(\frac{E_g}{Z_g}\right)^{1/4}E_m^{3/4}\text{ volts} \tag{29}$$

The watts loss in the core would be

$$W=\frac{e_{rms}^2}{R}=k\frac{16}{3\pi}\left(\frac{E_g}{Z_gR}\right)^{1/2}E_m^{3/2}\text{ watts} \tag{30}$$

It is possible to express these equations directly in terms of the material constants. Using the values for $E_m$ and $R$ developed in equations 69 and 74, Appendix I, equations 23, 25, 29, and 30 may be written as follows:

$$\frac{e_p}{NA}=k\,8.25\frac{(\omega B_m\rho)^{1/2}}{c}\left(\frac{NE_g}{lZ_g}\right)^{1/3}\times 10^{-4}\text{ v per turn per sq cm} \tag{31}$$

$$\theta_s+\theta_d=\frac{0.485c\left(\frac{\omega B_m}{\rho}\right)^{1/3}10^{-4}}{k\left(\frac{NE_g}{lZ_g}\right)^{1/3}}\text{ radians} \tag{32}$$

$$\frac{e_{rms}}{NA}=\sqrt{k}1.87\frac{\rho^{1/4}(\omega B_m)^{3/4}}{c^{1/2}}\left(\frac{NE_g}{lZ_g}\right)^{1/4}\times 10^{-8}\text{ v per turn per sq cm} \tag{33}$$

$$\frac{W}{G}=k0.29\frac{(\omega B_m)^{3/2}c}{\rho^{1/2}\delta}\left(\frac{NE_g}{lZ_g}\right)^{1/2}\times 10^{-12}\text{ w per gram} \tag{34}$$

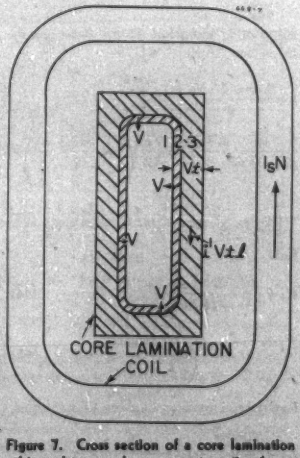


**Figure 7. Cross section of a core lamination subjected to very large magnetomotive forces**

The flux travels as a wave from the surface to the center. There has been little flux change in the area 1, in the relatively narrow strip 2, the flux is changing, and in the area 3, the iron is completely saturated

* It is interesting to note that $X$ does not appear in equation 23. This is a consequence of neglecting the additional terms of the form $1/n![(R/X)(\theta_s+\theta_d)]^n$ in the expansion by series to get equation 22. If $X$ were very small, this could not be done. In effect, $X$ has been assumed to be infinite with respect to $R(\theta_s+\theta_d)$, and in many problems this will be true. Therefore the voltage does not depend on $X$. This means that the change of flux in the core is limited entirely by the eddy currents, the permeability of the iron having a negligible effect.

METHOD B

As was mentioned earlier in this paper, high rates of change of flux in the core cause eddy currents which materially distort the flux distribution in the lamination. It is possible to write exact equations for the flux distribution in the lamination, assuming constant permeability. The condition is actually much different and vastly more complicated by the gradual yet enormous change in permeability. However, this solution will be used if the permeability value is chosen with this limitation in mind. In so doing, the mathematical analysis will be simplified if the flux density throughout the lamination is considered initially to be zero, instead of minus $\phi_m$, and to rise from zero to twice its saturation value.

It would be expected that the peak voltage would occur when the surface of the lamination was just saturating. Figure 4 shows a single lamination of steel of thickness $c$ and mean length of flux path $l$. It is assumed that the laminations are insulated from each other adequately and that the width of each lamination is large compared with its thickness. What occurs in this one lamination occurs in all of the others. This lamination is linked by a primary coil of $N$ turns carrying an effective alternating current of $I_s$ amperes. It is assumed that the transient will occur in a sufficiently short time that the slope of the current wave may be assumed constant and equal to its value at current zero. The equation for the primary coil magnetomotive force will be

$$\frac{0.4\pi\sqrt{2}I_sN\omega t}{l} \text{ oersted} \tag{35}$$

To agree with the change of flux from zero to twice maximum, this magnetomotive force will be assumed to be applied to the core at zero time. Let $x$ be the distance out, measured from the center of the lamination; let $H_x$ be the magnetomotive force at the center of the lamination; and let $i'$ be the eddy current density at any point in the lamination. The magnetomotive force at $x$ is

$$h = H_x + 0.4\pi \int_0^x i'\,dx \text{ oersteds} \tag{36}$$

$$\frac{\partial^2 h}{\partial x^2} = 0.4\pi \frac{\partial i'}{\partial x} \tag{37}$$

The induced voltage gradient in the lamination at any point $x$ is

$$e' = 10^{-8} \int_0^x \frac{\partial B}{\partial t}\,dx \tag{38}$$

$$B = \mu h \tag{39}$$

$$i' = \frac{e'}{\rho} = \frac{10^{-8}\mu}{\rho} \int_0^x \frac{\partial h}{\partial t}\,dx \tag{40}$$

$$\frac{\partial i'}{\partial x} = \frac{10^{-8}\mu}{\rho} \frac{\partial h}{\partial t} \tag{41}$$

Substituting equation 41 in equation 37,

$$\frac{\partial^2 h}{\partial x^2} = \frac{0.4\pi\mu 10^{-8}}{\rho} \frac{\partial h}{\partial t} \tag{42}$$

Since at the surface of the steel there will be no eddy currents to prevent the flow of flux, the magnetomotive force at the surface will be equal directly to that of the coil as given by equation 35. The

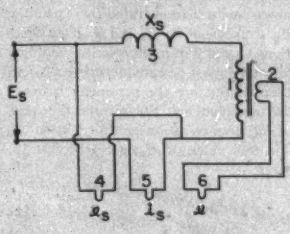


**Figure 8. Test circuit for measuring peak voltages**

The saturating reactor is 1, on which is wound a search coil, 2. The air-core loading reactor is 3, and 4, 5, and 6 are oscillograph elements

solution of equation 42 for these conditions (see Appendix III) is

$$h = \frac{0.4\pi\sqrt{2}I_sN\omega}{l}\left\{t + \sum_{s=1}^{s=\infty}(-1)^s \times \frac{16}{(2s-1)^2\pi^2} \frac{0.4\pi\mu 10^{-8}}{\rho}\left(\frac{c}{2}\right)^2\left(\cos\frac{2s-1}{2}\frac{\pi x}{\frac{c}{2}}\right) \times \left(1 - \epsilon^{-\frac{(2s-1)^2\pi^2}{4}\frac{\rho}{0.4\pi\mu\,10^{-8}}\frac{t}{(c/2)^2}}\right)\right\} \tag{43}$$

Let

$$K_h = \frac{hl}{0.4\pi\sqrt{2}I_sN\omega t} \tag{44}$$

$$K_t = \frac{\rho}{0.4\pi\mu 10^{-8}}\frac{t}{\left(\frac{c}{2}\right)^2} \tag{45}$$

Rewriting equation 43 using these values,

$$K_h = 1 + \sum_{s=1}^{s=\infty}(-1)^s \frac{16}{(2s-1)^2\pi^2} \times \frac{\cos\frac{(2s-1)}{2}\frac{\pi x}{c/2}}{K_t}\left(1 - \epsilon^{-\frac{(2s-1)^2\pi^2}{4}K_t}\right) \tag{46}$$

Figure 5 is a plot of equation 46 for various values of $K_t$. The total voltage induced in the coil would be

$$e = \frac{AN10^{-8}\mu}{\frac{c}{2}} \int_s^{c/2} \frac{\partial h}{\partial t}\,dx \tag{47}$$

Substituting the value of $h$ from equation 43 and simplifying by substituting $X$ and $K_t$ for their equivalents,

$$K_e = \frac{e}{\sqrt{2}I_sX} = 1 - \sum_{s=1}^{s=\infty}\frac{8}{(2s-1)^2\pi^2} \times \epsilon^{-\frac{(2s-1)^2\pi^2}{4}K_t} \tag{48}$$

Figure 6 is a curve of $K_e$ as a function of $K_t$. It can be seen that for large values of $K_t$, $K_e = 1$;

$$e = \sqrt{2}I_sX \tag{49}$$

In Appendix IV it is shown and from Figure 6 it can be seen that for small values of the variables,

$$K_e = \frac{2}{\sqrt{\pi}}\sqrt{K_t} \tag{50}$$

If the values for $\rho$ and $\mu$ from equations 75 and 72 of Appendix I are substituted in equation 45 and this value of $K_t$ substituted in equation 50,

$$e = I_s\left(\frac{8RX\theta}{3\pi}\right)^{1/2} \tag{51}$$

Comparing this equation with equation 7, this equation is seen to vary as the square root of time whereas equation 7, using the equivalent circuit, varies directly with time.

To find the angle at which the surface saturates, it is evident that the magnetomotive force at the surface is equal to that of the primary coil. From equation 37 then,

$$\mu\frac{0.4\pi\sqrt{2}I_sN\omega t_s}{l} = 2B_m \tag{52}$$

Substituting the value of $\mu$ and $B_m$ from equations 72 and 70 of Appendix I in equation 52,

$$\theta_s = \frac{2E_m}{I_sX} \tag{53}$$

Substituting this value of $\theta_s$ in equation 51,

$$e_p = \left(\frac{16I_sRE_m}{3\pi}\right)^{1/2} \tag{54}$$

Comparing this equation with equation 23 for the equivalent circuit analysis, the form is seen to be identical, except the coefficient, which is only 46 per cent as large.

Equation 54 is valid as long as the value of $K_t$ at the time the surface saturates, or $K_m$, is less than three-tenths.

the value of $I_s$ from equation 52 is substituted into equation 45,

$$K_{II} = \frac{5.06\rho B_m 10^{+8}}{\omega(\mu c)^2 (NI_s/l)} \qquad (55)$$

All the factors in equation 55 are constant except the permeability $\mu$. This varies over quite a range over the region of operation. $K_{II}$ is evaluated for the following example, which represents an average low-voltage current transformer, using a relatively low value for the permeability.

| | |
|---|---|
| $\omega = 377$ | $\rho = 60$ microhms per cm cube |
| $\mu = 1{,}000$ | $NI_s = 1{,}200$ ampere turns |
| $B_m = 12{,}000$ gausses | |
| $c = 0.033$ cm | |
| $l = 51$ cm | $K_{II} = 37.8$ |

Solving equation 44 for $h$, the flux density becomes

$$B = \mu h = \mu .4\pi\sqrt{2} I_s N\omega l \frac{K_h}{l}$$

Referring to Figure 5, if $K_I$ exceeds one, the value of $K_h$ will be between 0.55 and 1.0 so that the flux at every point will be at least 55 per cent of the maximum value. Considering that $\mu$ usually is not known within a factor of two, $B$ might be considered to be uniform for all practical purposes. Since method $A$ is based on uniform distribution of flux, we can say that when $K_I$ exceeds unity, the flux distribution is sufficiently uniform that method $A$ applies. In the example given, $K_I$ will exceed unity after a very small fraction of the transient time has elapsed, and thus method $A$ will be applicable.

The permeability is, of course, higher than 1,000 over part of the transient; however, it has been found that up to 1,000 ampere turns (rms) per inch, 29-gauge laminations, 60 cycles, the effect of nonuniform distribution of flux is slight and that method $A$ with the 0.85 correction factor is satisfactory. Above this value the correction factor decreases to a minimum of six-tenths at very high ampere turns.

Not included in this paper is the effect of capacity in the windings, which also begins to take effect when the peak of voltage is very short.

*Penetration of Flux Into the Lamination.* After the surface of the lamination is saturated, the reversal must spread into the center of the lamination in some manner. Figure 5 is a curve drawn to show the flux distribution for various rates of change of flux. It is apparent that the more rapidly the flux changes, the less the penetration of the flux into the center of the lamination. Also, the

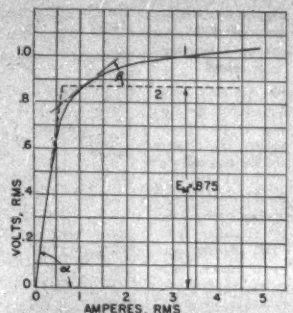


**Figure 9. Iron-core reactor excitation curve**

The actual curve is 1 and the assumed theoretical curve is 2. For a reactor with no air gaps, $E_m$ is approximately the point of tangency of a line drawn tangent to the knee of the curve such that tan $\beta = (\tan \alpha)/10$

width of the zone in which the flux is changing becomes smaller the more rapidly the change is made, and as a limit the wave front is almost vertical. As soon as the surface is saturated, the flux wave will start to penetrate the steel.

During this period the material can be divided into three zones: the center where there is little flux, the wave-front zone where the flux is changing, and the outer

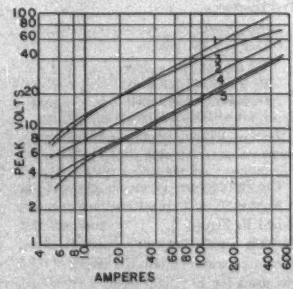


**Figure 10. Peak voltage of a saturating reactor**

1—Calculated curve for reactor only, using equation 12

2—Calculated curve for reactor only, assuming forcing of flux to surface of lamination, using equation 56

3—Test curve of reactor only which follows calculated curve 1 up to high values of current where it begins to bend over and approach curve 2

4—Calculated curve of reactor shunted by a 0.9-ohm resistor using equations 12 and 68

5—Test curve of reactor shunted by a 0.9-ohm resistor which follows the calculated curve 4 quite well

zone where the iron is saturated. The wave-front zone must travel in from the surface to the center. However, it must travel in with such a speed that it will induce enough voltage in the saturated zone behind it to circulate enough current to nearly balance the ampere turns of the primary coil. Enough ampere turns must be left over, though, to provide the magnetomotive force necessary for the wave-front zone. In the usual case, this will be small, and the generalization can be made that the eddy currents in the saturated zone must balance the primary ampere turns. If the flux travels in with a velocity of $v$ centimeters per second, referring to Figure 7, the flux in the saturated zone in a strip one centimeter wide would be

$$\phi_s = 2B_m vl \qquad (56)$$

The voltage gradient in the saturated zone would be

$$e' = (d\phi_s/dl)10^{-8} = 2B_m v 10^{-8} \text{ volts} \qquad (57)$$

The current density in the saturated zone is

$$i' = e'/\rho \text{ amperes per sq cm} \qquad (58)$$

The total current in the saturated zone is

$$i'vl = \frac{2B_m v 10^{-8} vl}{\rho} \qquad (59)$$

This is equal to the primary ampere turns

$$\frac{2B_m v^2 10^{-8} l}{\rho} = \sqrt{2} I_s \omega l N \qquad (60)$$

$$v = \left(\frac{I_s \omega N \rho 10^8}{\sqrt{2} B_m l}\right)^{1/2} \text{ centimeters per second} \qquad (61)$$

The total voltage induced in the primary coil will be

$$e = Ne' \frac{A}{c/2} \qquad (62)$$

If the value of $v$ from equation 61 is substituted in equation 57, and this value of $e'$ from equation 57 substituted in equation 62, and if the values of $\rho$ and $B_m$ from equations 75 and 70 of Appendix I are substituted in this equation for $e$, the peak voltage becomes

$$e_p = \left(\frac{4 I_s E_m R}{3}\right)^{1/2} \text{ volts} \qquad (63)$$

This is seen to be a value 12 per cent lower than that given by equation 54.

The voltage given by equation 63 is a flat-topped voltage. It is to be expected then that if a direct-current voltage were applied to a reactor, the current drawn would increase linearly with time,

$$i = \sqrt{2} \omega I_s t \qquad (64)$$

Substituting the value of $I_s$ from equation 63,

$$i = \frac{1.06 e_p^2 \omega t}{E_m R} \text{ amperes} \qquad (65)$$

*Shunting of Reactor With a Resistor.* The open-circuit voltage of a current transformer can be controlled by connecting a resistor to the secondary terminals. The value of the resistor can be very high relative to any normal burden so that its normal shunting effect is negligible, and yet considerable reduction in voltage may be obtained. Short-circuited bands of resistance metal sometimes used for phase-angle correction have exactly the same effect. The effect can be calculated by considering this resistor to be in parallel with $R$ (see Figure 2). The effective resistance of the burden resistance and the core resistance in parallel is

$$\frac{R_b R}{R_b + R} = \frac{R}{1 + \frac{R}{R_b}} \qquad (66)$$

From equation 66 it is seen that the new effective resistance is the core resistance divided by $1+(R/R_b)$.

From equation 23 it is seen that the peak voltage with a shunt resistor is equal to the peak voltage without, divided by the square root of $1+(R/R_b)$.

From equation 29 it is seen that the root mean square voltage with a shunt resistor is equal to the value without a shunt resistor divided by the fourth root of $1+(R/R_b)$.

These formulas are applicable only to method *A* where the core resistance can be separated out. If a resistor of any size shunts the reactor, it usually will make the formulas of method *A* even more applicable, as the eddy currents and flux are definitely separated.

## Test Data

Tests were made on a small ring-type iron-core reactor on alternating current to determine the peak voltages developed at various values of current. Tests also were made with the reactor shunted by a resistance to determine the effect of the resistor in reducing the peak voltages.

The circuit used is that shown in Figure 8. The series inductance for loading the circuit was an air-core reactor to make certain that it would have linear characteristics. A search coil was wound on the iron-core reactor and connected to an oscillograph element. The resistance of the oscillograph circuit was kept high so that its shunting effect on the peak voltages would be negligible. The line current and voltage also were connected to oscillograph elements. Tests were made on the reactor, measuring the currents and the peak voltages developed. These tests were rerun with a resistance shunted across the test reactor.

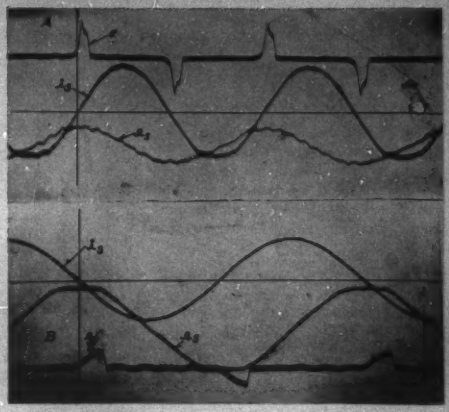

**Figure 11. Oscillograms of peak voltage of a saturated reactor**

Part *A* is for a reactor only; $I_s = 5.8$ amperes root mean square, 60 cycles; and the peak voltage is 9.1 volts

Part *B* is for the reactor shunted by a 0.9-ohm resistor; $I_s = 11.75$ amperes root mean square, 60 cycles; and the peak voltage is 5.9 volts

Part *A* shows flattening of the peaks of voltage from initial saturation of the surface and gradual penetration of the flux reversal. The minor peaks of voltage are caused by overtravel in the oscillograph. Part *B* corresponds to Figure 2C

Data for the circuit are as follows:

Power supply: 60 cycles alternating current, 0.2-ohm reactance

Air-core series reactor: 5.5 ohms

Test reactor:

Turns, $N = 16$

Losses at 0.483 volts

$VA = 0.159$ volt-ampere

$W$ (total) $= 0.129$ watt

$W$ (eddy) $= 0.049$ watt

$VAR = 0.0925$ volt-ampere reactive

Excitation curve per Figure 9

Shunt resistor: 0.9 ohm

The results are given in curve form in Figure 10. Typical oscillograms are shown in Figure 11. It was found that the best correlation was secured between calculated and test data if a factor of 0.85 was used for $k$.

## Calculations

Test reactor constants:

$$R = \frac{E^2}{W_a} = (0.483)^2/0.049 = 4.77 \text{ ohms}$$

$$X = \frac{E^2}{VAR} = (0.483)^2/0.0925 = 2.53 \text{ ohms}$$

From Figure 9, $E_m = 0.875$ volt

Calculations by sinusoidal voltage, method *A:*

1. $I_s = 5.8$ amperes, no shunt resistor

$$H_m = \frac{2 E_m Z_s R}{E_s}\left(\frac{X + X_s}{X X_s}\right)^2 = \frac{2 \times 0.875 \times 4.77}{5.8}\left(\frac{2.53+5.7}{2.53 \times 5.7}\right)^2 = 0.37$$

From Figure 3, $H_p = 0.68$, and using equation 12 for $e_p$,

$$e_p = k \frac{\sqrt{2} E_p X X_s}{Z_s (X + X_s)} H_p$$

$$e_p = 0.85 \frac{\sqrt{2} \times 5.8 \times 2.53 \times 5.7}{2.53 + 5.7} 0.68 = 8.3 \text{ volts}$$

2. $I_s = 11.75$ amperes with 0.9-ohm shunt resistor

$$R' = \frac{R R_b}{R + R_b} = 4.77 \times 0.9/(4.77 + 0.9) = 0.755 \text{ ohm}$$

$H_m = 0.0368$, $H_p = 0.25$

$$e_p = 0.85 \frac{\sqrt{2} \times 11.75 \times 2.53 \times 5.7}{2.53 + 5.7} \times 0.25 = 6.2 \text{ volts}$$

Calculations by simplified equation 23:

1. No shunt resistor:

$$e_p = k\sqrt{8 I_s E_m R} = 0.85\sqrt{8 I_s \times 0.875 \times 4.77} = 4.9\sqrt{I_s} \text{ volts}$$

2. With 0.9-ohm shunt resistor:

$$e_p = \frac{4.9\sqrt{I_s}}{\left(1 + \frac{R}{R_b}\right)^{1/4}} = \frac{4.9\sqrt{I_s}}{\left(1 + \frac{4.77}{0.9}\right)^{1/4}} = 1.95\sqrt{I_s} \text{ volts}$$

Calculations by flux distribution, method *B;*

$$e_p = \left(\frac{16 I_s E_m R}{3\pi}\right)^{1/4} = 2.66\sqrt{I_s}$$

Table I. Peak Secondary Open-Circuit Voltage Developed by Typical Current Transformers With 100 Per Cent Primary Current, Maintained Sinusoidal, 60 Cycles

| Type | Voltage Class | Current Ratio | Accuracy Rating | Peak Voltage |
|---|---|---|---|---|
| WE | 600 | 200/5 | 0.5-B-0.1, 0.2 | 175 |
| KO | 5,000 | 5/5-600/5 | 1.2-B-0.1, 0.5 | 475 |
| CT-5 | 5,000 | 5/5-600/5 | 0.3-B-0.1, 0.5, 2 | 1,800 |
| H-5 | 5,000 | 2,500/5 | 0.3-B-0.1, 0.5, 2 | 11,000 |
| *Ring | 46,000 | 1,200/5 | 2.5-L-400 | 6,700 |
| OPC-33 | 34,500 | 5/5-800/5 | 0.3-B-0.1, 0.5, 2 | 7,300 |
| OPC-66 | 69,000 | 5/5-800/5 | 0.3-B-0.1, 0.5, 2 | 8,300 |

* Multiratio bushing type for use on 46-kv bushing.

These calculated curves also are placed on Figure 10.

## Conclusions

The curves of Figure 10 which were calculated from method *A* (assumed uniform flux density in the lamination) show good agreement with the tests except at the higher values of current. At the higher values, the effect of crowding the flux to the surface becomes more noticeable. Presumably, at still higher currents the minimum value which would be calculated by method *B*, 46 per cent of that given by method *A* (when $K=1$), would be approached. The oscillograms all indicate a flattening of the top of the wave at higher currents, confirming the fact of a nearly uniform rate of flux change as the reversal travels in from the surface.

When the reactor is shunted by a resistor, accurate calculations are possible. The voltage peaks are nearly true triangles.

The method for fairly exact calculation of peak voltage will permit design of apparatus for minimum values of voltage, as far as possible, and design of proper protection against these voltages. One of the useful results of the method is that the energy available in the voltage peaks can be determined.

Table I lists the maximum open-circuit voltage that can be developed at rated current in certain typical current transformers. The voltage varies approximately as the square root of the current.

## Symbols

$A$ = net core area, sq cm
$B$ = instantaneous flux density, gauss
$B_m$ = maximum flux density, gauss (Figure 2)
$c$ = core lamination thickness, cm
$e$ = instantaneous voltage of reactor, volts
$e_p$ = peak induced voltage of reactor, volts
$e_{rms}$ = root mean square value of reactor peak voltage, volts
$e'$ = eddy voltage gradient in lamination, volts/centimeter
$E_s$ = system root mean square voltage, volts
$E_m$ = root mean square voltage reactor will induce, volts, at $B_m$ normal frequency
$G$ = core weight, grams
$h$ = instantaneous magnetomotive force in lamination, oersteds
$H_m$, $H_n$ = see equation 9 and equation 19, respectively
$H_a$ = instantaneous magnetomotive force at center of lamination, oersteds
$H_p$, $H_q$ = see equation 11 and equation 20, respectively
$i_r$ = instantaneous current through equivalent $R$ of reactor, amperes
$i_L$ = instantaneous current through equivalent $L$ of reactor, amperes
$i_s$ = instantaneous system current, amperes
$i'$ = eddy current density in lamination, amperes per square centimeters
$I_s$ = system root mean square current, amperes
$k$ = experience factor for peak voltage, about 0.85
$K_a$ = see equation 48
$K_b$ = see equation 44
$K_s$ = see equation 45
$K_{ss}$ = see equation 55
$l$ = mean length of flux path, centimeters
$L$ = equivalent inductance for reactor, henries
$L_s$ = system inductance, henries
$N$ = reactor turns
$R$ = equivalent resistance for reactor, ohms
$R_b$ = resistance of shunt resistor, ohms
$R_s$ = system resistance, ohms
$t$ = time, seconds
$v$ = velocity of flux wave, centimeters per second
$W$ = core loss, watts
$W_e$ = eddy component of core loss, watts
$x$ = distance as measured from center of lamination, centimeters
$X$ = equivalent reactance for reactor, ohms
$X_s$ = system reactance, ohms
$Z_s$ = system impedance, ohms
$\delta$ = core density, grams per cubic centimeter
$\theta = \omega t$, radians
$\theta_d$ = angle before current zero at which core desaturates, radians
$\theta_s$ = angle after current zero at which core saturates, radians
$\mu$ = core permeability
$\rho$ = core resistivity, ohms per centimeter cube
$\phi$ = total flux in core, lines
$\phi_m$ = maximum total flux in core, lines
$\omega = 2\pi$ frequency, radians per second

## Appendix I. Reactor Constants

At low frequencies, the equivalent circuit for the reactor is as shown in Figure 2, with an inductance and resistance in parallel. The primary definition of $E_m$, the maximum alternating voltage at system frequency that the reactor will induce, will be taken as equation 8. Using this as the definition has the advantage that if any correction must be applied to the theoretical values of the peak voltage, the duration of the pulse will be known to change in the opposite direction approximately the same percentage. This follows from equation 8, for the area under the voltage curve is a constant, regardless of the shape of the voltage curve. It usually will not be convenient to determine $E_m$ in this manner, but from the sample tests it was found that the construction shown in Figure 9 gave a value of $E_m$ that agreed with the oscillograms. Referring to Figure 9, a curve is drawn with the alternating-current voltage as a function of the alternating-current exciting current on rectangular-co-ordinate paper for a core with no air gaps. A line then is drawn tangent to the knee of the curve with a slope one-tenth the slope of the initial straight part of the curve. The point of tangency then gave $E_m$ approximately.

The equivalent reactance $X$ and the eddy-loss resistance, $R$, of the reactor can be determined from values of $I$, $E$, $W$ (total watts loss), and $W_e$ (watts eddy-loss) corresponding to some convenient point on the initial straight part of the excitation curve.

$$X = \frac{1}{\left[\left(\frac{I}{E}\right)^2 - \left(\frac{W}{E^2}\right)^2\right]^{1/2}} \text{ ohms} \qquad (67)$$

$$R = \frac{E^2}{W_e} \text{ ohms} \qquad (68)$$

The values of $E_m$, $X$, and $R$ can be calculated from material constants, or the material constants can be calculated from test results by the following formulas:

$$E_m = \frac{\omega N B_m A 10^{-8}}{\sqrt{2}} \text{ volts} \qquad (69)$$

$$B_m = \sqrt{2} E_m / \omega N A \ 10^{-8} \text{ gauss} \qquad (70)$$

$$X = \omega 0.4\pi N^2 \mu A \ 10^{-8}/l \text{ ohms} \qquad (71)$$

$$\mu = Xl/(\omega 0.4\pi N^2 A \ 10^{-8}) \qquad (72)$$

$$W_e = \frac{E^2}{R} = \frac{(\omega N B A \ 10^{-8})^2}{2R}$$

$$= (\delta l A)\left[\frac{\omega^2 B^2 c^2 \ 10^{-16}}{24\delta\rho}\right] \text{watts} \qquad (73)$$

$$R = 12N^2 A \rho/(lc^2) \text{ ohms} \qquad (74)$$

$$\rho = Rlc^2/(12N^2 A) \text{ ohms per centimeter cube} \qquad (75)$$

## Appendix II. Calculation of $\theta_d$

To calculate the angle at which the core starts to desaturate,

$$B_m = 0.4\pi N i \mu / l \qquad (76)$$

For time near current zero, the equation for the line current is approximately

$$i_L = \sqrt{2}\omega I \phi \tag{77}$$

$$\omega t = \theta_d = \frac{B_m l}{0.4\pi N \mu \sqrt{2} I_L} \tag{78}$$

Substituting the values of $B_m$ and $\mu$ from equations 70 and 72,

$$\theta_d = \frac{E_m}{I_L X} \text{ radians} \tag{79}$$

## Appendix III. Solution of Equation 43

Referring to "Mathematics of Modern Engineering," by Doherty and Keller,[5] page 282, the partial differential equation of a cable with distributed constants of series $R$ and shunt $C$ per unit of length is

$$\frac{\partial^2 e}{\partial x^2} = RC \frac{\partial e}{\partial t} \tag{80}$$

Comparing with equation 42, these are seen to be identical if

$$RC = \frac{0.4\pi\mu\, 10^{-8}}{\rho} \tag{81}$$

Since the terminal conditions are the same, the solution for voltage on a cable may be used for the solution of magnetomotive force for iron if the above substitution for $RC$ is made.

The foregoing reference gives the solution on pages 285–7 for a unit function voltage applied to a cable of finite length with the receiving end open-circuited. The solution desired is that with a voltage which increases uniformly with time. This can be found very simply from the preceding solution by the following method. On page 286, equation 339 is given for the operational solution for voltage:

$$e = \frac{E \cosh \pi x}{\cosh \pi l} 1 \tag{82}$$

The solution desired for a voltage that increases linearly with time would be of the form

$$e = \frac{E' t \cosh \pi x}{\cosh \pi l} 1 \tag{83}$$

The operational form for $t$ is $1/p$, though

$$e = \frac{E' \cosh \pi x}{p \cosh \pi l} 1 \tag{84}$$

The solution of equation 84 is

$$e = E' \int_0^t \left( \frac{\cosh \pi x}{\cosh \pi l} 1 \right) dt \tag{85}$$

Hence if the solution on page 287 is integrated from zero to $t$, it will be the solution for a voltage that increases linearly with time. This leads directly to equation 43.

## Appendix IV. Solution of Equation 50

It is not at all evident from an inspection of equation 48 that it does approach equation 50 for low values of $t$. Letting $z^2 = K_1$ in equation 48,

$$\frac{dK_2}{dz} = \frac{8}{\pi^3} \sum_{s=1}^{s=\infty} \frac{\pi^2 z_s}{4} \epsilon^{-\frac{(2s-1)^2 \pi^2 z^2}{4}} \tag{86}$$

If $z$ approaches zero, this can be replaced by the integral

$$\frac{dK_2}{dz} = 4z \int_{s=0}^{s=\infty} \epsilon^{-\frac{(2s+1)^2 \pi^2 z^2}{4}} ds = \frac{4z}{\pi z} \frac{\sqrt{\pi}}{2} \tag{87}$$

$$\frac{dK_2}{dz} = \frac{2}{\sqrt{\pi}} \tag{88}$$

And for values of $z$ near zero,

$$K_2 = c_1 + \frac{2z}{\sqrt{\pi}} = c_1 + 2\frac{\sqrt{K_1}}{\sqrt{\pi}} \tag{89}$$

To show that $c_1$ is equal to zero, substitute in a point on the straight part of the curve of Figure 6.

## Appendix V. Complete Solution for $i_L$

If $e_g = \sqrt{2}E_g \sin(\omega t + \psi)$, and if it is assumed that the line current has returned to its sinusoidal value after the peak during the previous half-cycle, the current through the equivalent inductance $L$ is

$$i_L = K_1 \epsilon^{\lambda_1 t} + K_2 \epsilon^{\lambda_2 t} + \frac{\sqrt{2}E_g}{Z_1} \sin(\omega t + \psi - \beta) \tag{90}$$

$$\psi = \tan^{-1}(X_g/R_g) \tag{91}$$

$$\beta = \tan^{-1} \frac{\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}}{\frac{R}{X}\cdot\frac{R_g}{X_g} - 1} \tag{92}$$

$$Z_1 = \frac{XX_g}{R}\left[\left(\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}\right)^2 + \left(\frac{R}{X}\cdot\frac{R_g}{X_g} - 1\right)^2\right]^{1/2} \tag{93}$$

$$\frac{2\lambda_1}{\omega} = -\left(\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}\right) - \left[\left(\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}\right)^2 - 4\left(\frac{R}{X}\cdot\frac{R_g}{X_g}\right)\right]^{1/2} \tag{94}$$

$$\frac{2\lambda_2}{\omega} = -\left(\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}\right) + \left[\left(\frac{R}{X_g} + \frac{R}{X} + \frac{R_g}{X_g}\right)^2 - 4\left(\frac{R}{X}\cdot\frac{R_g}{X_g}\right)\right]^{1/2} \tag{95}$$

$$K_1 = \frac{\sqrt{2}E_{g0}}{\lambda_2 - \lambda_1} \epsilon^{\frac{\lambda_2 \theta_d}{\omega}} \times \left[\frac{\cos(-\theta_d + \psi - \beta)}{Z_1} - \frac{\lambda_2 \sin\theta_d}{\omega Z_1} - \frac{\lambda_2 \sin(-\theta_d + \psi - \beta)}{\omega Z_1}\right] \tag{96}$$

$$K_2 = \frac{\sqrt{2}E_{g0}}{\lambda_1 - \lambda_2} \epsilon^{\frac{\lambda_2 \theta_d}{\omega}} \times \left[\frac{\cos(-\theta_d + \psi - \beta)}{Z_1} - \frac{\lambda_1 \sin\theta_d}{\omega Z_1} - \frac{\lambda_1 \sin(-\theta_d + \psi - \beta)}{\omega Z_1}\right] \tag{97}$$

$$Z_g = (R^2_g + X^2_g)^{1/2} \tag{98}$$

$\theta_d$ is found from equation 79. To use equation 90, the time of saturation, $t_s$, is found by setting $I_L$ equal to $+\sqrt{2}\, I_s \sin\theta_d$ and solving for $t_s$. The peak voltage is the value of $L(di_L/dt)$ at $t_s$. There appears to be no simple manner in which to secure $t_s$, and the nature of the problem does not warrant the labor as compared with the approximate methods developed in the paper.

## References


1. Peak Voltages Across Saturating Reactances, H. Fahnoe, A. J. Maslin. *Electric Journal*, March 1932, page 120.

2. Peak Voltages on Saturating Reactances in Three-Phase Circuits, E. L. Harder. *Electric Journal*, March 1932, pages 124–9.

3. Overvoltage Protection of Current Transformer Secondary Windings and Associated Circuits, R. H. Kaufmann, G. Camilli. AIEE Transactions, volume 62, 1943, July section, pages 467–72.

4. Evolution of Standard Lines of Current Transformers for High Overcurrent Capacity, E. C. Wentz. AIEE Transactions, volume 63, 1944, September section, pages 658–62.

5. Mathematics of Modern Engineering, volume I (book), R. E. Doherty, E. G. Keller. John Wiley and Sons, New York, N. Y., 1936. Pages 282–7.

6. Characteristics of Current Transformers on Open Circuit, W. R. Woodward. *Electric Journal*, February 1918, pages 48–50.

# A Tunable Rejection Filter

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**Synopsis:** The theory and design of a tunable bridge-type narrow-band rejection filter are given for the general case, considering elements with dissipation. Range of adjustment and effect of manufacturing variations are discussed with the help of impedance circle diagrams. Approximate attenuation formulas for various levels of attenuation are derived, and a convenient graphical method of studying performance is suggested. A formula for the effective width of a special arrangement of two filters in tandem is derived.

IN COMMUNICATION and allied branches of electrical engineering, it is frequently necessary to use a filter with a narrow stop band to reject a single interfering frequency. It is the purpose of this paper to describe the theory of operation and methods for design and reduction to practice of such a device which has proved to be valuable at frequencies from 1,000 to 20,000 cycles per second. The principles of the device are equally applicable at much lower[1] and at much higher frequencies.

The familiar bridge circuit of Figure 1, frequently employed as a delay circuit, is the basic arrangement for the narrow band rejection filter. An elementary explanation of the device[2] sets forth that each of the bridge arms is resonant at the reject frequency and the inevitable dissipation is such that the four arms become equal resistances at the reject frequency, and the bridge is therefore balanced and the undesired frequency rejected. The impedance circle diagram of Figure 2 illustrates this concept. In the practical case, resistances are functions of frequency, and although the line and circle loci are distorted, the distortion is not enough to destroy the usefulness of the concept, since most of the distortion is in those parts of the loci far from resonance. The circle applies to the parallel resonant arms and the vertical line to the series resonant arms. The familiar half-energy points of the resonance curve are found at the intersections of the 45-degree lines with these loci, which Kennelly has called the quadrantal points.[2] Both loci contain arrowheads to indicate the direction in which the tip of the impedance vector moves as the frequency increases. The narrowness of the stop region near the balance point $b$ is a function of the velocity with which these vector loci are traced as the frequency is varied. Since they are traced most rapidly near resonance, which occurs at $b$, and particularly since they are traced in opposite directions near the balance point, a very narrow stop band is realized, the width of which is found to vary inversely as the circuit $Q$. A device of this kind rejecting 1,100 cycles per second has been inserted in a telephone circuit with negligible loss of intelligibility.

The construction of such a device with the line exactly tangent to the circle and the resonance of all arms of the bridge occurring at the same frequency is difficult and unnecessary, since closely similar performance can be realized with the balance condition illustrated in Figure 3. In Figure 3, the balance point does not occur at resonance, and the series and parallel circuits have different resonant points shown at $r_1$ and $r_2$. There are two possible balance conditions indicated by the intersection points $b_1$ and $b_2$, and either can be obtained by adjusting the resonant frequencies. The impedances of all four bridge arms at balance are equal both in magnitude and angle. This procedure requires much less accurate control of the resistance, which is often less predictable than the reactance, and assures a balance, since a balance is always possible if the line and the circle intersect. If the tangent condition is attempted, any increase in dissipation results in the separation of the two loci, and no balance is possible, although some attenuation can be obtained where the loci are nearest together.

## Range of Adjustment

A considerable range of reject frequencies is obtainable with any given set of coils. Consider, for example, a coil that has no dissipation other than d-c resistance. The position of the straight line locus then is independent of frequency. The diameter of the circle locus is proportional to the square of the resonant frequency according to the equation,

$$\text{Resonant resistance} = \omega^2 L^2 / R_{DC}$$

If a rejection filter of this type, operating as shown in Figure 3, is tuned to successively lower frequencies, the circle locus will decrease in size until the tangent condition of Figure 2 is reached. With any further decrease in frequency, the loci will separate and no balance will be possible. If the frequency is increased above that corresponding to Figure 3, the diameter of the circle will increase as the square of the frequency, and the balance points $b_1$ and $b_2$ will become farther and farther separated from the resonance $r_3$. Balance is still possible, since the loci intersect, but it is not usually desirable to use this condition, since it produces an

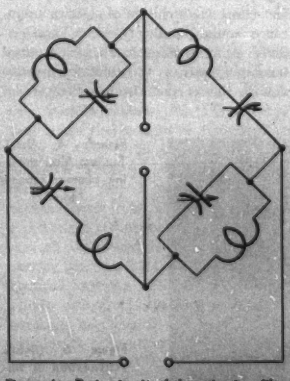

Figure 1. Basic circuit of the rejection filter

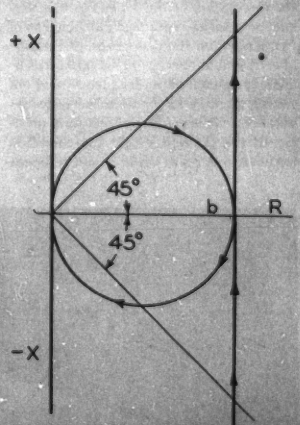


Figure 2. Impedance diagram, limiting case

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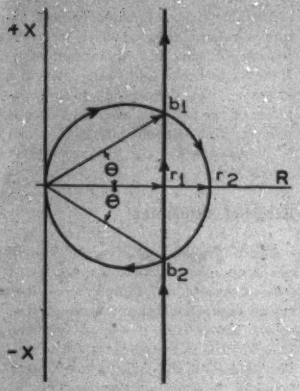


Figure 3. Impedance diagram, general case

effect very similar to reducing the $Q$. If an arbitrary standard were set up requiring the parallel resonant resistance to be not more than twice the series resonant resistance (line passing through center of circle), then the frequency range of adjustment in this case would be limited to $\sqrt{2}$ to 1. However, as bad a condition as this is seldom met in practice, and a range of adjustment approaching two to one is practicable in most cases. The range realized depends on the variation of dissipation with frequency and on the need for maximum narrowness of stop band.

Theoretically, infinite range of adjustment is obtained when the product of the series resonant and shunt resonant $Q$'s is constant. As an illustration, let the dissipation of the series resonant circuit be a series resistance independent of frequency and the dissipation of the parallel resonant circuit be a shunt resistance independent of frequency and, of course, slightly larger than the series resistance. This results in constant product of the $Q$'s and is also the condition for no distortion of the loci, and resonant resistance independent of frequency. Such a combination could be tuned to reject any frequency with equally good results. Practically, such a combination of properties is seldom available without loss of stability or circuit $Q$, and one is likely to find the resonant resistance of desirable components varying with the frequency, introducing some distortion of the loci and limiting the range of adjustment to about two to one.

## Practical Circuit Arrangement

In practice it is usually preferable to modify the circuit of Figure 1 to that of Figure 5, where inductances with the same letter designations are on the same core. Imperfect coupling between windings is not often serious, the principal effect being the inclusion of a series inductance in the parallel resonant branches. Since at frequencies much greater than balance frequency, the useful frequencies flow to the receiver through the parallel resonant arms of the bridge, the series inductance will limit the high frequency response. In practice this limitation is not severe, since the parallel resonant inductance is a small one if the $Q$ is ten or greater; leakage inductance can easily be made a small fraction of the total; and consequently a wide pass band above the reject frequency will exist. It has been found convenient to select transformation ratios that make the three capacitors marked $C$ of equal capacity.

Since the stop band is very narrow, it is usually desirable to use trimmer capacitors which permit about one per cent adjustment of capacity (Figures 4 and 5). Larger air capacitors with precision mechanical drives are convenient for greater range. Figure 5 shows input and output coupling transformers to match impedance levels.

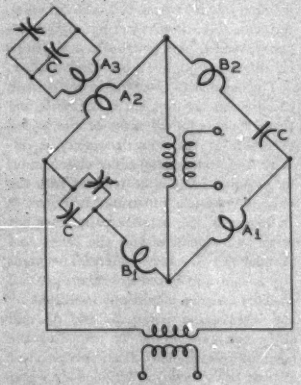


Figure 5. Practical circuit of the rejection filter

## Attenuation Formulas and Graphs

The attenuation of all such reject filters is shown as a function of frequency in Figures 6 and 7. These curves can be represented for attenuations greater than ten decibels by the following equation derived in the appendix:

$$\alpha = 20 \log_{10} (K/W) \qquad (1)$$

These curves are universal curves, since the constant $K$ has the same dimensions as the variable $W$, the width of the stop band on the frequency scale at attentuation $\alpha$. In other words, the frequency scale may be thought of as plotted in $K$ units as indicated in Figure 7.

Figure 4 (left). Tandem filter showing trimmer capacitors

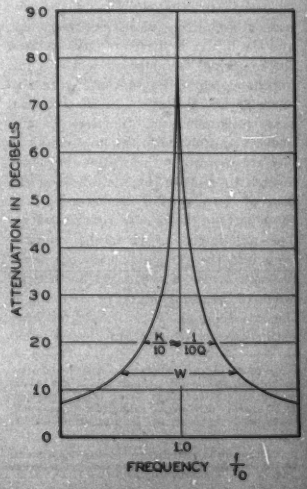


Figure 6 (right). Attenuation of single rejection filter

In Figure 7 the dotted curve at $A$ indicates either an imperfect balance or noise present in the test equipment, and the dotted extension at $B$ indicates a graphical method of determining $K$. If the data are plotted with width in cycles per second as abscissa instead of $K$ units as abscissa, the intersection of the straight line with the axis gives the actual value of $K$ in cycles per second.

A slightly more complicated empirical equation useful down to three decibels is

$$\alpha = 20 \log_{10} [K/W + 1/(1+K/W)] \qquad (2)$$

$K$ can be determined graphically from the curves, as indicated, or computed by formula 25. As shown in the appendix, a better approximation for attenuations between one-tenth decibel and three decibels is given by

$$\alpha = 20 \log_{10} [1 + (1/2)(K/W)^4] \qquad (3)$$

The attenuation curve is rather difficult to measure at large attenuations, since either or both low frequency noise and harmonics of the reject frequency tend to reduce the apparent attenuation. Another difficulty is the requirement of very small frequency steps near the reject frequency. A cycles increment dial on a beat frequency oscillator is a convenience for these tests.

Figure 7 suggests the use of two crossed rejection filters as a discriminator in frequency modulation receivers, provided some ten decibels of minimum loss can be tolerated.

## Two Reject Filters in Tandem

If a rejection band wider than that provided by one section of this type of filter is required to secure sufficient band width to reject a narrow band of frequencies rather than a single frequency, it may be desirable to widen the stop band by using two or more filters in tandem, each filter rejecting a slightly different frequency. In some cases this arrangement may be found advantageous to preserve the required attenuation if the circuit elements are not sufficiently stable. Two sections result in a characteristic of the type shown in Figure 8. Using equation 1, it can be shown (see appendix) that

$$W_b/W_s = \sqrt{2 \text{ antilog}_{10} (\alpha_0/20)} \qquad (4)$$

where $W_s$ is the width of one filter at the attenuation $\alpha_0$. The increase in width is shown by Table I, which shows a very large relative increase at high attenuations.

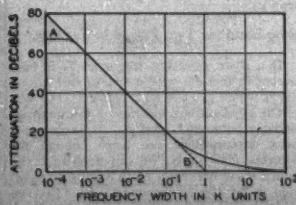


Figure 7. Graphical method of determining $K$

## Stability Measurements

In the construction of these filters, it is essential that all components, including the resistances of the circuit, have good stability with respect to temperature, humidity, and voltage. Silvered-mica capacitors with air trimmers and powdered-iron cores made of Carbonyl E iron have been found to be of satisfactory stability. The final stability coefficient of the rejection frequency and attenuation is a complex function of the separate coefficients of the filter components and also of whichever of the two possible balance points is selected. One model designed to be tunable from 3,000 to 4,800 cycles per second was adjusted to 70 decibels attenuation at 3,600 cycles per second, and subjected to temperatures from 55 to 100 degrees Fahrenheit. The peak attenuation decreased about five decibels and the frequency at which the peak occurred changed less than two cycles per second. In any individual case, the various temperature coefficients can be made to counteract each other if components of both positive and negative coefficients are available.

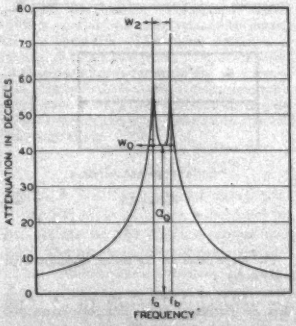


Figure 8. Attenuation characteristic of tandem rejection filters

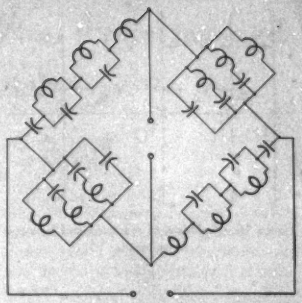

Figure 9. Multiple frequency rejection filter

## Relation to Filter Theory

While it is obviously appropriate to call this device a filter, since it has pass and stop frequency regions, the attenuation in the stop band is explained only by the resistances present, while conventional filter theory excludes resistance and deals with reactances. The device illustrated in Figure 1 is an all-pass network with no attenuation at any frequency when considered as a conventional filter. It is only when resistance is considered as in Figures 2 and 3 that the attenuation region appears. If the resonant frequencies of the series tuned and shunt tuned arms are slightly separated, then an attenuation band is predicted by filter theory; but only small attenuations will be realized when reactances of the size given by the design equations are used.

The extension of these principles to multiple reject frequencies in a single section is illustrated in Figure 9. Such a device results in an economy of elements but requires variable inductors as well as capacitors, and the adjustments of various reject frequencies are not independent, so that a more practical solution may be the use of simpler sections in tandem. The bridge arms in Figure 9 are shown in a canonic form.[4]

## Coil Design

Since the $Q$ of the circuit determines the narrowness of the rejection band and

Table I. K Units

| Db | $W_s$ | $W_b$ | $W_b/W_s$ |
|---|---|---|---|
| 20 | 0.1 | 0.447 | 4.47 |
| 34 | 0.02 | 0.20 | 10. |
| 40 | 0.01 | 0.141 | 14.1 |
| 60 | 0.001 | 0.0447 | 44.7 |
| 74 | 0.0002 | 0.02 | 100. |

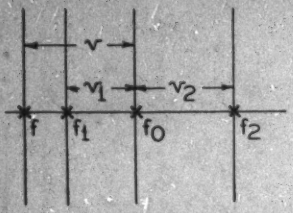


**Figure 10. Relation of resonant and balance frequencies**

the capacitors are responsible for little of the loss in the circuit, the design of coils with a specified high $Q$ is fundamental. Another important factor results from the large ratio between the inductances of the parallel and series tuned branches. Equation 32 shows this ratio to be approximately $Q^2$ and therefore may be as high as 100,000 or more. This indirectly determines the impedance level of the bridge, since the series-tuned inductances should not be so large as to lose $Q$ from distributed capacity and leakage effects, and the parallel-tuned inductance should not be so small as to require too small a number of turns, since it is impossible to get close coupling to the tuned winding with less than one turn, and the change of one turn in a small number results in a limited choice of inductance.

Typical windings are illustrated in Figure 11. Notice that in Figure 11A most of the space is allotted to the tuned winding to get maximum $Q$ and consequently minimum width of the reject band.

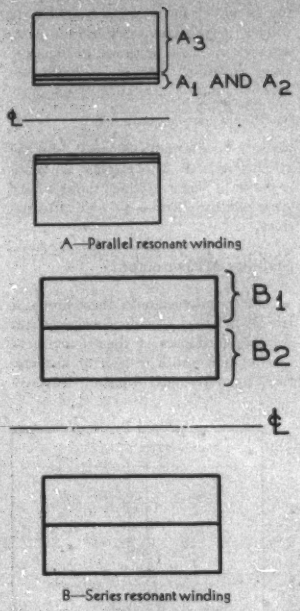


**Figure 11**

## Appendix

### Attenuation Formulas

The propagation constant of a bridge or lattice network is given by[4]

$$\alpha = 20 \log_{10} [(\sqrt{ZY}+1)/(\sqrt{ZY}-1)] \quad (5)$$

and balance of the bridge is obtained when $ZY = 1+j0$. Two approximate forms of the equation for the propagation constant are of interest in this application. The first is applicable when

$$ZY = 1+jT \qquad T \ll 1$$

and results in

$$\alpha = 20 \log_{10} (4/T) \quad (6)$$

The other is applicable when

$$ZY = -S+jT \qquad T \ll S$$

and results in

$$\alpha = 20 \log_{10} (1+T/S^{3/2}) \approx 17.37 T/S^{3/2} \quad (7)$$

The impedance of the series resonant arm is given by

$$Z_1 = -jX_1[(f_1/f)-(f/f_1)+jR/X_1] \quad (8)$$

where

$$X_1 = 2\pi f_1 L_1$$

and the admittance of the parallel resonant arm is given by

$$Y_2 = -jB_2[(f_2/f)-(f/f_2)+jG/B_2] \quad (9)$$

where

$$B_2 = 2\pi f_2 C_2$$

and $R$, $X$, $G$, $B$, $Z$, and $Y$ have their usual Ohm's law meaning, and $f_1$ and $f_2$ are the resonant frequencies of $Z_1$ and $Y_2$ respectively. The appearance of the expressions may be simplified by writing them as

$$Z_1 = -jX_1(m_1+j1/Q_1) \quad (8a)$$

$$Y_2 = -jB_2(m_2+j1/Q_2) \quad (9a)$$

Using equations 8a and 9a,

$$Z_1Y_2 = -X_1B_2[m_1m_2-1/Q_1Q_2+j(m_1/Q_2+m_2/Q_1)] \quad (10)$$

where

$$X_1B_2 = 4\pi^2 f_1 f_2 L_1 C_2 = f_1L_1/f_2L_2 \quad (11)$$

At balance

$$\sqrt{ZY} = 1+j0 \quad (12)$$

Consequently balance conditions are

$$m_1/Q_2 = m_2/Q_1 = 0 \quad (13)$$

and

$$1/X_1B_2 = 1/(Q_1Q_2)-(m_1m_2) = 1/Q_a^2 \quad (14)$$

Calculation of $m_1$ and $m_2$ near balance may be made easier if $f/f_1$ is written (see Figure 10) as

$$f/f_1 = 1-(v-v_1)/f_1 = 1-a \quad (15)$$

and similarly

$$f/f_2 = 1-(v-v_2)/f_2 = 1-b \quad (16)$$

Then

$$m_1 = 1/(1-a)-(1-a) = 2a+a^2+a^3+\ldots. \quad (17)$$

$$m_2 = 1/(1-b)-(1-b) = 2b+b^2+b^3+\ldots. \quad (18)$$

and

$$m_1m_2 = 4ab+2a^2b+2ab^2+2a^3b+a^2b^2+2ab^3+\ldots. \quad (19)$$

Near balance,

$$m_1m_2 = -1/Q_1Q_2 \approx -1/Q_a^2 \quad (20)$$

Since $Q_1$ and $Q_2$ vary slowly and $m_1m_2 \ll 1/Q_1Q_2$

$$Z_1Y_2 \approx 1-jQ_a^2(m_1/Q_2+m_2/Q_1) \quad (21)$$

Equation 6 is applicable, giving

$$\alpha = 20 \log_{10} [4/Q_a^2(m_1/Q_2+m_2/Q_1)] \quad (22)$$

Farther from balance, $m_1m_2 \gg 1/Q_1Q_2$ and

$$Z_1Y_2 \approx -Q_a^2m_1m_2-jQ_a^2(m_1/Q_2+m_2/Q_1) \quad (23)$$

Equation 7 is applicable, giving

$$\alpha = 20 \log_{10} \left[1+\frac{Q_a^2(m_1/Q_2+m_2/Q_1}{(Q_a^2\ m_1m_2)^{3/2}}\right] \quad (24)$$

The simplified formulas 1 and 3 can be obtained from 22 and 24 by letting $Q_1 = Q_2$, which allows $v_1$ to be taken equal to $v_2$. Letting the definition of $K$ be

$$K = 2f_0Q/Q_a^2 \quad (25)$$

Equation 22 becomes

$$\alpha = 20 \log_{10} (2f_0Q/WQ_a^2) = 20 \log_{10} (K/W) \quad (22a)$$

and equation 24 becomes

$$\alpha = 20 \log_{10} [1+(1/2)(Q_a/Q)^2(K/W)^2] \quad (24a)$$

which is identical with equation 3 when $Q_a = Q$.

### Stop Band for Two Filters in Tandem

If a filter rejecting frequency $f_a$ is connected in tandem with a similar one rejecting $f_b$ where $f_b - f_a = W_0$ (Figure 8), the sum of the attenuations will have a minimum $\alpha_0$ midway between $f_a$ and $f_b$. If the component attenuations are large enough for formula 1 to apply, we can determine the width $W_0$ of the reject band having attenuation $\alpha_0$ by the following process. Let the width at frequency $f$ (less than $f_a$) of the filter rejecting $f_a$ be called $W$. Then the

filter rejecting $f_2$ has width $W+2W_2$ at frequency $f$.

At the central minimum

$$\alpha_2 = 20 \log_{10} (K/W_2)^2 \quad (26)$$

Let $f=f_1$ and $W=W_1$ at the edge of the stop band having attenuation $\alpha_2$. Then

$$\alpha_2 = 20 \log_{10} (K/W_1)[K/(W_1+2W_2)] \quad (27)$$

For a single section with attenuation $\alpha_2$,

$$\alpha_2 = 20 \log_{10} (K/W_2) \quad (28)$$

Consequently, from equations 26, 27, and 28,

$$W_1(W_1+2W_2) = W_1^2 = KW_2 \quad (29)$$

and since

$$W_1 = W_2 - W_3 \quad (30)$$

equation 29 can be rewritten to give

$$W_3/W_2 = \sqrt{2K/W_2} = \sqrt{2}\ \text{antilog}_{10}\ (\alpha_2/20) \quad (31)$$

and

$$W_3/W_2 = \sqrt{2} \quad (31a)$$

### Design Equations

Combining equations 11 and 14,

$$L_1/L_2 = f_2 Q_a^2/f_1 \quad (32)$$

The second equation to permit solving for $L_1$ and $L_2$ is obtained by setting the quotient of equations 8 and 9 equal to $R_3^2$, where $R_3$ is the resistance of generator and load. This results at pass band frequencies in

$$L_1 L_2 = R_3^2/4\pi^2 f_1 f_2 \quad (33)$$

Combining equations 32 and 33, we get

$$L_1 = Q_a R_3/2\pi f_1 \quad (34)$$

and

$$L_2 = R_3/2\pi f_2 Q_a \quad (35)$$

$L_1$ and $L_2$ are the inductances actually effective in the bridge arms. If the coupled arrangement of Figure 5 is used, the coupling coefficients increase the inductances as follows:

$$L_1 = (Q_a R_3/2\pi f_1)2/(1+k_1) \quad (34a)$$

and

$$L_2 = R_3/2\pi f_2 Q_a k_2^2 \quad (35a)$$

where $k_1$ is the coupling coefficient between windings $B$ in Figure 5 and $k_2$ is the coupling coefficient between the tuned winding $A$ and either of the $A$ windings included in the bridge arms.

## References


1. Control of Inductive Interference to Telegraph Systems, J. W. Milnor. AIEE Transactions, volume 59, 1940, August section, pages 469–74.

2. United States Patent 2,173,722.

3. Electrical Vibration Instruments (book), A. E. Kennelly. Macmillan Company, New York, N. Y., 1923.

4. Electrical Networks, volume II, E. A. Guillemin. John Wiley and Sons, Inc., New York, N. Y., 1935.


# Protection of Pilot Wires From Induced Potentials


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**Synopsis:** The use of pilot-wire relays for protection of power transmission circuits usually requires a reliable pilot channel which is free of any induced potentials which may cause transient voltages to appear between wires even though they may be of relatively low magnitude. This is particularly true in the case of pilot relays using a sequence network in which a single-phase alternating voltage is applied to the pilot wires. Conventional methods of protection, such as those used on telephone circuits, are not suitable. As a result it frequently has been necessary to install special pilot circuits which are insulated for voltages far in excess of their normal operating voltage to insure reliable operation. This paper describes a method of protection which provides reliable and satisfactory operation of a-c pilot channels through low-voltage telephone-type cable, even though the cable may be subject to induced potentials high enough to operate discharge gaps.


PILOT WIRES used for relay protection of 66-kv transmission lines on the system of The Dayton Power and Light Company in several cases parallel 12-kv distribution feeders. Lead-sheathed telephone cable is used. In overhead sections it is installed on the same poles with the 12-kv lines and in underground sections occupies adjacent ducts to 12-kv underground feeders.

Figure 1 is a map of the protected 66-kv circuits and the routes of the pilot wires and their paralleling 12-kv 4-wire feeders. Figures 2 and 3 show typical configurations of the exposures. All cable sheaths, including the pilot-wire cable sheaths, are bonded at every manhole. Power cable sheaths serve as neutral conductors and are grounded at the substation and at all terminals or risers. The pilot-wire cable sheaths are grounded at each terminal, at the dispatcher's office, and at every riser. In overhead sections the power system neutral is multigrounded but not bonded to the telephone cable sheath, except at risers. The 12-kv system neutral is solidly grounded at substations.

A schematic diagram of the pilot relay circuits, as originally installed, is shown in Figure 4. During fault conditions, single-phase alternating potentials are applied to the pilot wires by the positive- and zero-sequence networks in the pilot relays. When unequal currents flow in and out of the line section, unequal voltages are produced by the relay networks and the resultant difference in current flows through the operating coils. During faults external to the protected section, the potentials produced by the relay networks at opposite terminals act in series, circulating current through the restraint coils and pilot wires to prevent tripping.

The condition thus is established that when the voltage between pilot wires is built up to a critical value by reason of unequal currents flowing in and out of the line section, tripping occurs. It is also true that if this critical voltage is exceeded by reason of some extraneous voltage impressed between pilot wires, tripping will occur.

The maximum current and voltage impressed on the pilot wires by the relays is approximately 100 milliamperes and 60 volts. The minimum alternating potential required between pilot wires to cause the relay contacts to close is approximately 15 volts.

### Incorrect Operations

Early experience in the operation of the relays disclosed the following types of incorrect operations:

1. Potentials induced by ground faults on 12-kv circuits paralleling the pilot wires caused incorrect tripping of 66-kv breakers. An example of this type of incorrect operation occurred during a 12-kv line-to-ground fault at industrial plant $A$ (see Figure 1). Induced potentials appeared on the paralleling pilot wires, causing operation of the carbon block protectors. The discharge through these protectors, being unequal, resulted in a potential appearing between pilot wires, which caused tripping of all 66-kv circuits supplying Webster substation.


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2. Normal load currents in paralleling 12-kv 4-wire feeders caused induced potentials in the pilot wires which circulated current through the alarm relays and gave incorrect alarms. Potentials of 20 to 30 volts between pilot wires and ground frequently were encountered. This potential caused current to flow through the distributed capacitance of the pilot wires to ground, some of which returned through the grounded mid-point of the supervisory relay transformer. The capacitors connected between mid-points of the insulating transformer and the ground served to by-pass some of this current. However, this did not entirely correct the difficulty.

3. Normal load currents in paralleling 12-kv 4-wire feeders caused induced potentials in the pilot wires, which incorrectly tripped 66-kv breakers if one pilot wire accidentally became grounded. Grounding of one pilot wire causes any induced potential to appear between pilot wires. If the potential exceeds 15 volts, tripping results. Several operations of this type occurred when workmen accidently grounded one of the pilot wires while working on other circuits in the cable.

As a result of these difficulties, a series of investigations was conducted to determine the magnitude of the extraneous potentials appearing on the pilot wires and to devise a suitable means of correcting these troubles.

## Field Tests

Field tests were carried out on the underground exposure from Webster to industrial plant *A* and on the overhead exposure from Hoover to industrial plant *B*. These tests were designed to determine the magnitude of the longitudinal voltages with which a protective scheme would have to deal. With the power circuits disconnected from their normal busses, a 230-volt test voltage was applied to cause ground fault current to flow in the exposures. From these tests, mutual impedance values were found as shown in Table I. Applying these factors to calculated values of fault current, the maximum longitudinal pilot-wire voltage was found to be 1,650 volts. With this information, the problem was resolved into designing a protective scheme meeting certain requirements for satisfactory operation of the relays.

## Pilot-Wire Protective Scheme

The fundamental requirements of the protective scheme are as follows:

1. The protective scheme should function to discharge properly any extraneous potentials imposed in the pilot wires without resulting in any appreciable potential difference appearing between pilot wires. Any such potential between wires should not exceed 15 volts.

2. The voltage from a pilot wire to ground (or other wires in the cable) must be limited to 700 volts crest value during any system disturbance to avoid exceeding the voltage rating of the cable.

3. The protective scheme should permit normal operation of the pilot relays during periods in which the protective equipment is functioning. This is necessary to insure correct relay operation in case of faults involving both 66-kv and 12-kv circuits simultaneously.

4. The proper functioning of the pilot-wire supervisory relays, which indicate to the operators the presence of open- or short-circuit conditions in the pilot wires, must be maintained.

5. The protective equipment used must automatically restore the circuits to normal after its operation.

With these requirements in mind, it appeared that a solution could be found

**Table I. Pilot-Wire Voltages to Ground Resulting From Faults on Paralleling 12-Kv Feeders**

| | *Underground Exposure | Overhead Exposure |
|---|---|---|
| Mutual impedance in ohms per mile (ratio of pilot-wire voltage per mile of exposure to ground fault current in power circuits) | 0.096−<br>0.100 | 0.262−<br>0.265 |

* Fault current in either or both power cables to industrial plant *A*.

**Table II. Laboratory Measurements of Pilot-Wire Currents and Voltages**

| | |
|---|---|
| Current in ground lead of arresters, amp | 18.4 |
| Applied longitudinal pilot-wire voltage, v rms | 1,500 |
| Voltage from pilot wire to ground at terminals of insulating transformer, v rms | 393 |
| Voltage between pilot wires at terminals of insulating transformer, v rms | 2.6 |

**Table III. Zero-Phase-Sequence Constants of Underground Cables From Webster to Industrial Plant *A***

| | One Cable | Two Cables |
|---|---|---|
| Voltage impressed between paralleled phase conductors and ground, v | 210 | 197 |
| Total current, amp | 832.8 | 532 |
| Power input, kw | 49 | 80.6 |
| Length of cable, miles | 1.87 | 1.87 |
| $Z_0$ in ohms per phase per mile | 0.710+ *j*0.722 | 0.472+ *j*0.334 |

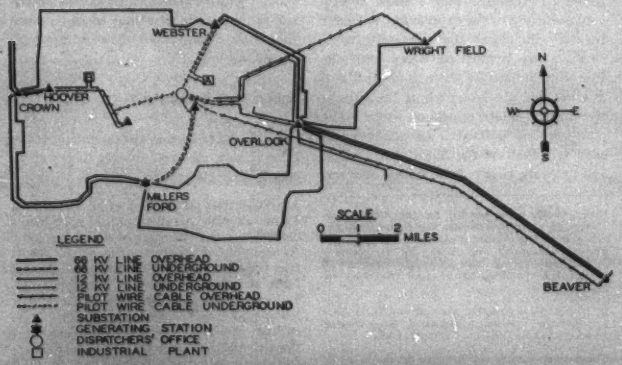


**Figure 1. Map of 66-kv lines protected by pilot-wire relaying showing routes of pilot-wire cables and inductive exposures to 12-kv power feeders**

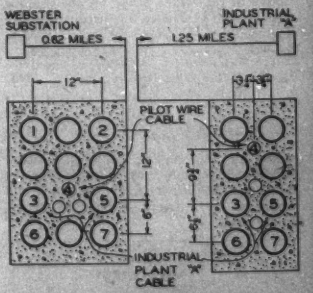


**Figure 2. Details of underground ducts between Webster substation and industrial plant *A***

Cables 1, 2, 3, 5, 6, and 7 are 3-conductor 500,000-cir-mil shielded sector-type, with 13/64-inch conductor insulation and 8/64-inch lead sheath. Cable 4 is 51-pair number 19 0.075-inch-lead 0.95-inch-outside-diameter pilot-wire cable

**Table IV. Phase Angle of Pilot-Wire Voltages to Ground Resulting From Faults on Paralleling 12-Kv Feeders**

| | Underground Exposure | Overhead Exposure |
|---|---|---|
| Approximate angle the pilot-wire voltage leads the power conductor current, deg | 0 | 31 |

**Table V. Rise in Substation Ground Potential During 12-Kv Faults to Ground**

| | Webster Substation | Hoover Substation |
|---|---|---|
| Type of 12-kv feeder faulted | Underground | Overhead |
| Rise in substation ground potential in volts per ampere of fault current | 0.0064 | 0.0578 |
| Maximum calculated rise in ground potential for faults near substation, v | 130 | 600 |

**Table VI. Pilot-Wire Voltages to Ground and Rise in Substation Ground Potential for 66-Kv Faults to Ground**

| | Webster Substation | Crown Substation |
|---|---|---|
| Fault current to substation ground bus, amp | 1,788 | 1,460 |
| Pilot-wire voltage to substation ground with opposite end grounded, v | 13 | 174 |
| Rise in substation ground potential, v | 130 | 334 |

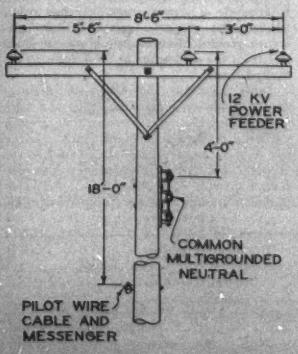


**Figure 3. Typical pole top detail showing 12-kv power feeder, secondary, and 51-pair number 19 0.075-inch-lead 0.95-inch-outside-diameter pilot-wire cable, supported by 5/16-inch high-strength galvanized steel messenger**

in the application of the principle used in the American Telephone and Telegraph Company's number 223-A retardation coil, used for the reduction of metallic voltages on open-wire carrier lines. It consists simply of modified drainage coils with middle connections isolated from ground by gaps. When the gaps discharge the assembly functions as a drainage coil.

Preliminary laboratory tests were made using coils of various excitation characteristics and several types of discharge gaps.

The connection diagram adopted from these tests is shown in Figure 5. It will be noted that the mutual reactors at the substations are connected to the mid-terminals of the relay insulating transformers instead of across the pilot wires. This connection was adopted in order to cause a minimum change in pilot-wire shunt impedance during discharge. However, if circumstances required connection across the pilot wires or additional protectors between terminals, the shunt impedance could be made high enough to cause only slight decrease in the sensitivity of the pilot relays.

A mutual reactor was selected, each winding of which has an exciting impedance of approximately 11,500 ohms at 200 volts. This value of impedance was considered sufficiently high to result in a negligible change in the sensitivity of the pilot relays during gap discharge. This value of impedance also was considered sufficiently high to insure satisfactory operation of the protector tubes without causing excessive excitation currents in the reactors.

A gas-filled protector tube was selected which had the following characteristics:

| | |
|---|---|
| A-c rms breakdown voltage, v | 300–500 |
| Maximum discharge current for two seconds, amp | 50 |
| Average arc drop, v, d-c | 20–30 |

The tube is capable of repeated discharges without material change in characteristics.

## Final Laboratory Tests

Equipment was connected in the laboratory as shown in Figure 5. Resistors were used to simulate pilot-wire resistance.

### Test Number 1

With protector tubes removed at points *B* and *C* and terminals 2 and 3 connected at *B*, test potential was applied between the mid-point of the mutual reactor at *B* and ground. Oscillograph elements were connected to measure quantities as shown in Table II. This test indicated that with maximum longitudinal voltage induced on the pilot wires, the potential between wires was sufficiently low to prevent incorrect relay operation. Also the voltage between pilot wire and ground was well within its insulation rating.

### Test Number 2

This test was made to determine the effect of protector discharges on the sensitivity of the pilot relays.

1. With all protector tubes short-circuited, no appreciable change in the sensitivity of the pilot relays was detected.

2. A similar test was performed with current flowing in the pilot wires and protective equipment simulating discharge currents. This was accomplished by short-circuiting the protector tube at *A* and applying test potential between the mid-point of the mutual reactor at *B* and ground, with terminals 2 and 3 connected. The results of this test indicated no appreciable change in pilot relay sensitivity with currents in each pilot wire up to three amperes.

## Field Application

On the basis of the laboratory tests, the 66-kv pilot-relay circuits were equipped

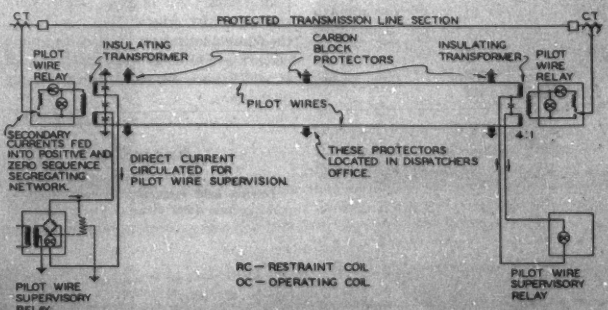


**Figure 4. Schematic diagram of pilot-wire relaying as originally installed**

Table VII. Substation Ground Resistance

| | Webster Substation | Crown Substation | Hoover Substation |
|---|---|---|---|
| Substation ground resistance, ohms | 0.14 | 0.87 | 0.36 |

with the new protective devices. The laboratory tests described indicated that this equipment satisfactorily would eliminate incorrect relay operations caused by ground faults on paralleling 12-kv 4-wire feeders.

The second-mentioned difficulty, involving improper operation of the alarm relays, was corrected by the relay manufacturer. A grounding resistor is used with a grounded center tap connected across the output of the rectifier in the alarm relay, instead of grounding the center tap of the transformer supplying the rectifier unit, as shown in Figure 4. This measure prevented induced potentials from causing current to flow through the rectifier and operating coil of the alarm relay.

The foregoing modifications did not eliminate completely potential between pilot wires resulting from normal load currents in paralleling 12-kv 4-wire feeders. This potential appears when a pilot wire becomes accidentally grounded. However, the voltage was reduced below the 15-volt operating level of the relays by the use of the grounding resistor on the alarm relay and the removal of the capacitors connected between the mid-points of the insulating transformer and ground. This resulted in a considerable increase in the impedance between the pilot wires and ground at this point, thereby reducing the potential between pilot wires when one wire becomes grounded. The net result of this change, as determined from field measurements, is a reduction in the potential between pilot wires of approximately 50 per cent for equivalent values of induced potential.

## Final Field Tests

The operation of the protective devices was tested by staged ground faults on the 12-kv circuit at the end of the overhead exposure between Hoover substation and industrial plant *B*. Oscillograph measurements were made of the voltage between pilot wires and from pilot wire to ground, and of the fault current. With a fault current of 2,400 amperes, the voltage between pilot wires at Hoover substation was less than two volts, and from pilot wire to ground was 320 volts rms. The calculated longitudinal voltage induced for this value of fault current is approximately 1,000 volts. During the tests, protector tubes discharged, but no pilot-wire relay operations occurred.

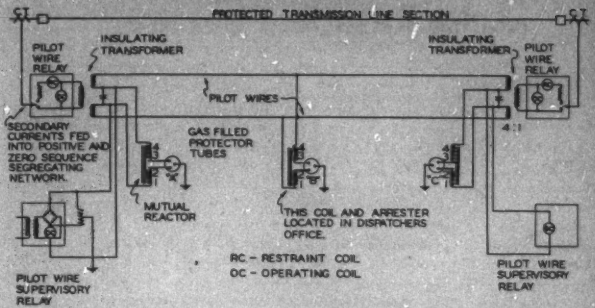


Figure 3. Schematic diagram of pilot-wire relaying equipped with new protective devices

## Conclusions

The coils and protector tubes described were obtained from a limited selection of available material, and the laboratory tests were intended to indicate their suitability rather than to determine the most satisfactory design.

Field tests were not conducted on simultaneous 12-kv and 66-kv faults. However, on the basis of the laboratory tests, it is believed that such faults will be relayed correctly.

Since the installation of the protective equipment, several faults have occurred on 12-kv circuits at locations which had formerly caused incorrect operations of the pilot relays. All of these faults were cleared satisfactorily without operation of the 66-kv pilot relays. During this same period, several 66-kv faults occurred, all of which were cleared properly by the pilot relays.

## Appendix

During field tests it was convenient to make certain other measurements which did not bear directly on the problem at hand. Some of these data are included in the hope that they may add to the knowledge on these subjects.

Table III shows the results of measurements made to determine the zero-phase-sequence impedance of the underground cables from Webster to industrial plant *A*, illustrated in Figure 2. The duct line is removed fairly well from pipe lines or other known underground structures.

Table IV shows the results of measurements made to determine the phase position of the induced potential with reference to the current in the power conductor. These measurements were made by a voltage triangulation method using a high resistance voltmeter. A reference voltage in phase with the power conductor current was obtained by connecting a noninductive resistor to the secondary of the current transformer in the power circuit.

Table V shows the results of measurements made to determine the rise in substation ground potential caused by 12-kv faults to ground. The measurements were made between the substation ground bus and reference grounds driven approximately 1,000 feet from the substation at 90 degrees to the faulted feeder.

Table VI shows the results of measurements made to determine the pilot-wire voltage and the rise in substation ground potential during ground faults on the 66-kv system. Ground faults were applied at Webster and Crown substations to the substation ground bus. The rise in substation ground potential was measured with reference to a remote driven ground located approximately 1,000 feet from the substation and as near 90 degrees to the 66-kv lines as possible.

Table VII shows the results of ground resistance measurements of substation ground busses made with a ground resistance tester using two remote reference grounds.

# Marine Radar for Peacetime Use

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MILITARY RADAR systems by the score have been developed for such varied purposes as surface search, aircraft detection, height finding, gunfire control, range finding, and other wartime uses not as yet released from the classified categories.

In most of these systems, the prime function was connected in some way with locating the enemy accurately, judging his course, speed, and strength, and getting this knowledge quickly enough to take appropriate counteraction. The sooner such data were accumulated and evaluated, the stronger offensive (or defensive) measures were possible. For this reason, design parameters that affected cost, complexity, or operator skill were less important than those which governed range, accuracy, resistance to gunfire shock, etc.

The relative importance of these factors was reflected necessarily into the space and power requirements of the military equipment, and the very design elements that permitted excellent military radar are often those which make for an unsuitable peacetime radar.

Let us forget, for the moment, the spectacular achievements of radar during the past few years and look ahead to its function as a safety device for civilian use. Among the many jobs that have been envisioned for this branch of electronics, there is perhaps none as important as that of marine radar. From the economic viewpoint alone, the intrinsic value of ships, cargo, and time lost because of poor visibility mounts to enormous proportions. This waste, plus the attendant loss of life, can be reduced to a very small amount by the use of radar equipment properly designed for the job.

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## Design Requirements for Peacetime Radar

The design variables which are controllable include at least the following: reliability, simplicity, accuracy of range and bearing, cost, ease of maintenance, resolving power (on adjacent objects) maximum range, minimum range, appearance, accessibility of components, and size.

In either case, military or civilian, reliability comes first. Cost is a minor point in military designs, a major one in civilian designs. Simplicity of installation and operation is not too important on a battleship where dozens of technically trained men are available. A cargo ship, however, operating in a highly competitive field, must consider any extra personnel from the accountant's viewpoint and use a radar capable of operation by the regular complement of officers.

Maximum ranges of military equipments frequently exceed 100 miles and require appropriate high power for such a range. A passenger ship is concerned much more with an obstacle which may be only several miles away; hence a large equipment is neither justified nor desirable.

The minimum range of a destroyer's radar may well be a mile or two, on the theory that an enemy must be discovered long before he can approach that close. The minimum range of a radar for a cargo ship is required to be less than a ship length—the shorter the better, in order that navigation may be accomplished safely in congested harbors.

And so, all through the whole list of design factors, there must be a new philosophy of design to create suitable radar equipment for our commercial uses. Our peacetime designers must not say, "Who is shooting at my ship from over the horizon?" but rather, "Can this device permit my present complement of personnel to avoid collisions and to obtain fixes from charted landmarks?"

## One Design of Commercial Radar

Early in 1943, experiments were conducted on a Great Lakes ore boat, using a modification of a military ship-borne "search radar." From six months' operating data, two outstanding facts stand out:

1. Despite some inherent weaknesses, common to all radar systems, the installation proved to be a highly useful navigational tool.

Figure 1 (left). Rotating antenna assembly

Figure 2 (right). Electronic navigator console

Figure 3 (left). Speed-regulated motor-alternator

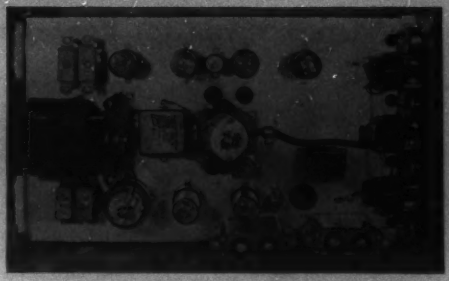


Figure 6 (right). Typical removable chassis of electronic navigator console

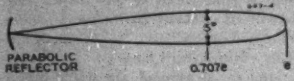



Figure 4. Typical beam pattern in horizontal plane, showing five degrees width at half-power points

2. It was too complex for nontechnical personnel to operate.

From these early experiences, plus a study of several hundred service reports from military installations, the present electronic navigator was evolved. Figures 1, 2, and 3 show the three units of the complete equipment: the antenna system, console, and motor-alternator, respectively.

The antenna system is driven by a gear-motor located in the antenna base, or "pedestal," and the slatted reflector rotates continuously at 10 rpm. The surface of this reflector is a truncated paraboloid of revolution and is proportioned to project a beam 5 degrees wide and 15 degrees high. (A fully parabolic reflector of the same width would project a conical beam 5 degrees wide, with the resultant danger of lost targets when the ship rolled.) Note that these figures do not imply that there is zero radiation outside the angles mentioned; the accepted method of measuring beam width is at the half-power points, as shown in Figure 4.

Figure 5. Electronic navigator console with front cover removed, showing removable chassis

The console, Figure 2, contains the transmitter, receiver, cathode ray tube, sweep circuits, pulsing circuits, rotating field mechanism, appropriate power supplies, and controls. During normal operation, seven controls are available to the operator. Having adjusted the instrument and selected the desired range scale (2, 6, or 30 miles) no further manipulation is required unless it is desired to take a bearing on some specific object. In this case a knob is provided to control a radial bearing line which can be caused to bisect the object in question and thus read its azimuth on a scale around the circumference of the cathode ray tube.

All other controls which are required for initial adjustment during installation are accessible to recognized service personnel only and are covered by a locked panel. Figure 5 shows these controls and also the test jacks and the panels of the various removable chassis. In case of trouble with any chassis, it is possible for the service engineer to substitute an entire chassis in a minute and repair the original one at leisure. Figure 6 illustrates a typical chassis removed from the console.

Figure 7 is a block diagram of the radar circuits and emphasizes the relative simplicity as compared with usual military designs. The pulse generator of Figure 8 is a blocking oscillator whose recurrence rate is determined by a network $Z$ and resistors $R_1$ and $R_2$. (Most blocking oscillators employ only a capacitor in place of a network.) The function of the lumped-constant line $Z$ is to provide a delay in the discharge time so that the tube may be allowed to conduct its full saturation current for a definite time interval, as shown in the pulse shape of Figure 9, which depicts the voltage across the primary of transformer $T_1$. This transformer

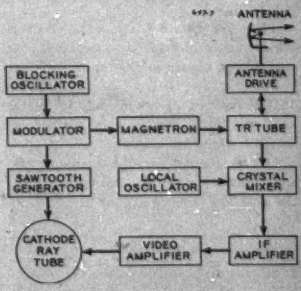



Figure 7. Block diagram of circuits

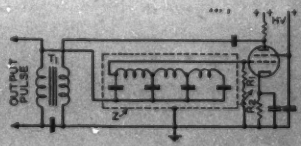



Figure 8. Pulse-forming circuit

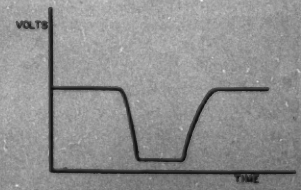



Figure 9. Pulse shape

is so connected as to provide regenerative feedback for the oscillator, and thus the cycle is repetitive and at a rate controlled by variable resistor $R_3$. The simplicity and reliability of this circuit makes it particularly suitable, for this application. The pulses formed by the blocking oscillator are amplified by a suitable pentode and used to drive the magnetron oscillator which operates in the 10-centimeter region. See Figure 10. The modulation transformer ($T_1$) permits the magnetron filament to be operated 5,000 volts above ground, for this is the order of magnitude of the amplified pulse voltage. A tap on the modulation transformer allows the modulator tube to be properly loaded.

The pulse is considerably less than one microsecond in length and repeats at about 1,000 cycles per second. Thus the peak power delivered to the magnetron is of the order of kilowatts, though the average power is but a few watts.

Referring again to Figure 7, the output of the magnetron is delivered to the antenna through the transmit-receive (T-R) tube, the function of which is to protect the receiver during transmitter pulses and to close off the path to the magnetron during the receiving time, between pulses.

The returning echo from the "target" is collected by the parabolic reflector, focused on the antenna dipole, and carried through the transmit-receive tube to the receiver circuits. In the crystal mixer the returning signal is caused to beat with the output of a klystron local oscillator, the resultant frequency being about 30 megacycles. This is amplified by a wide-band intermediate-frequency amplifier, detected and further amplified by the video amplifier, and thence applied to the control grid of the cathode ray tube.

In the meantime the antenna assembly has been rotating continuously, and its

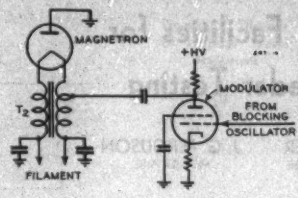



Figure 10. Modulator and magnetron circuits

motion has been transmitted by a very compact and simple Selsyn system to the rotating magnetic deflection coil located around the neck of the cathode ray tube. Impressed across this rotating coil is the sawtooth sweep voltage which provides a linear radial time axis. Time, too, is synchronized with the transmitter, and as both the outgoing pulse and the returning echo travel at the speed of light, this time axis is really a distance measure.

The over-all result is that as the radial time (that is, distance) axis rotates, any returning echo will intensify a portion of this axis as the rotating antenna "beams" on the target. With an ordinary cathode ray screen, the bright flashes of light would indicate the presence of reflecting objects, but the operator would have to remember where the flashes occurred, obviously an undesirable disadvantage.

Hence, a long-persistence screen is used, in which the cathode ray first excites a short-persistence phosphor, which in turn causes a second long-persistence phosphor to glow. This glow persists for a long enough time to "remember" a scene until rekindled by the next rotation of the radial sweep.

Since the resultant illumination is in the form of a plan view of the surrounding area, with one's own ship at the center, the system is commonly termed "plan presentation indicator," or simply "P.P.I."

Figure 11 illustrates such a picture, showing land masses, open water, buoys, and ships in the vicinity of Matinicock Point in Long Island Sound. For comparison, the actual chart of that area is printed beside the radar chart.

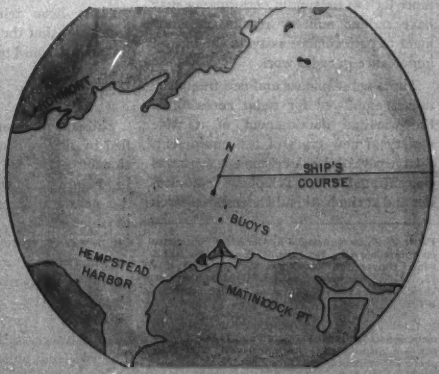
There are simpler presentation systems, but they require more skill in interpretation. It was felt that the plan presentation indicator picture "spoke the language" of the navigator better, since it shows him the data in familiar chart form. This has been borne out in actual experience, both with skilled navigators and students in training.

## Practical Results

The particular design described above has completed an 8-months' test installation on the United States Maritime training ship, AMERICAN MARINER. During that time, several hundred persons have operated the equipment. This group has included military personnel highly trained in radar principles, captains of cargo ships, shipowners, shipyard executives, tugboat captains, river pilots, navigators, trainees, and even deckhands.

From their varied reactions, it has been possible to create a design well suited for the job, unhampered by excessive gadgeting, and capable of operation by nontechnical personnel. Further, it has been possible to spread the idea that radar is not a cure-all scheduled to usurp the functions of existing instruments; rather it is a very powerful aid to those instruments, performing new duties previously left to guess work or chance.

Figure 11. Comparison of radar picture and actual navigation chart



# Techniques and Facilities for Microwave Radar Testing

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**Synopsis:** Methods and devices are described for testing microwave radar equipment in the radio frequency range from about 500 megacycles to 25,000 megacycles and at associated video frequencies. In general, the same instruments and techniques are applicable also in testing microwave communication systems.

THAT RADAR equipments are marvels of ingenuity has long since become common knowledge. This ingenuity is reflected, however, in complexity of circuits. A rough index of this complexity is found in the number of vacuum tubes, which for a single radar set may range from 50 to 250. Notwithstanding the most careful design, it is easy for the radar performance to become impaired under operating conditions.

Not only is radar complex, but its performance criteria are less tangible than those of conventional communication systems. Ordinary radio is to some extent self-testing in that reception of intelligible speech or signals frequently constitutes a sufficient check of satisfactory performance. With radar, the greater the range coverage and the more accurate the data, the more valuable the information is likely to be. However, the working range may fall to a fraction of the possible maximum, or some other degradation or malfunctioning may occur, with nothing in the operation of the radar equipment to tell that this has happened. Since lack of maximum performance may have serious military results, measurement of performance assumes the utmost importance in radar work.

The new techniques and new frequency ranges employed for radar necessitated the wartime development of a wide variety of new types of test equipment. A large part of this development work was concentrated at Bell Telephone Laboratories and at the National Defense Research Council's Radiation Laboratory at Massachusetts Institute of Technology, working in close co-ordination with one another and with the technical services of the Army and the Navy. In the manufacture of radar test equipment, Western Electric took a major part. This article discusses the techniques of radar testing and describes the types of test gear developed by Bell Laboratories and manufactured by Western Electric. These cover the radio frequency range from about 500 megacycles to 25,000 megacycles, together with associated video frequencies.

Because of its importance during the war, emphasis has been placed on the testing of microwave radar equipment. However, similar methods and instruments also have been employed in the testing of microwave communication systems, and such applications can be expected to increase. In this situation the developers and users of microwave communication systems are fortunate in that almost all of the techniques and devices developed for radar testing are equally applicable to communication systems. This is even true of the video units, which are useful in connection with pulse-modulated telephone systems and amplitude-modulated or frequency-modulated television systems.

So many persons, both within and outside Bell Laboratories, have contributed to the developments described that the authors have reluctantly reached the conclusion that the assignment of individual credit should not be attempted.

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## Requirements

Subsequent discussion may be simplified by first reviewing briefly the operation of a typical radar set, as shown in Figure 1. Under the control of d-c or so-called video pulses from the modulator, short pulses of radio frequency energy are delivered by the magnetron transmitter to a highly directive antenna, ordinarily arranged to scan a section of space. Energy reflected from an object or "target" in the path of the beam is intercepted by the same antenna. The received pulses or echoes are converted to an intermediate frequency by heterodyning against a local oscillator, the frequency of which may be automatically controlled.

To enable the same antenna to serve for both transmitting and receiving, a transmit-receive tube or transmit-receive switch is usually provided. This consists of a partially evacuated resonant cavity containing a spark gap which breaks down during the transmitted pulse, thus preventing the transmitted power from injuring the sensitive receiver. A receive-transmit (RT) tube, consisting of a similar resonant cavity and spark gap, may be provided to prevent absorption of the received signal by the transmitter. After amplification and detection of the received signal, the resultant video pulses are applied to an indicator which may present information in any of several different ways. Customarily, the direction of the target (determined by antenna orientation) and its range (determined by reflection interval, 10.7 microseconds per mile) are shown. The system may be used merely for searching, or for fire control, bomb direction, or other functions, with additional equipment as required.

### Types of Tests and Test Sets

Figure 2 shows an early assemblage of radar test equipment for the 10-centimeter range, initially produced in 1942, which has seen wide usage.

The more important types of tests required in radar work, either at radar operating locations or at centralized service points, are:

1. Over-all performance (range capability).
2. Transmitter power.
3. Receiver sensitivity.
4. Transmitter frequency.
5. Transmitter spectrum.
6. Standing wave ratio.
7. Radio-frequency (RF) envelope.
8. Receiver recovery.
9. Automatic frequency control (AFC) tracking.
10. Intermediate-frequency (IF) alignment.
11. Video wave shapes.
12. Range calibration.
13. Computer calibration.

The principal types of test sets required for carrying out the above are:

1. Signal generators.
2. Echo boxes.
3. Frequency and power meters (separate or combined).
4. Standing wavemeters.

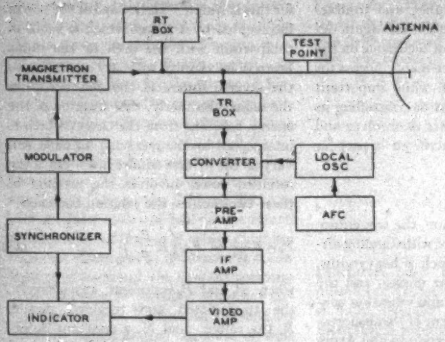



**Figure 1. Diagram of typical radar equipment**

5. RF loads.
6. Oscilloscopes.
7. Video dividers and loads.
8. Range calibrators.
9. Computer test sets.
10. Spectrum analyzers.

Various auxiliary testing instruments also are employed, including vacuum tube testers, intermediate-frequency signal generators, audio oscillators, flux meters, and so forth. Before discussing the above tests and devices individually, some of the requirements for radar test equipment, especially those requirements resulting from military usage, will be summarized.

### Generality of Application

Radar sets perform a great variety of functions, including search and surveillance, gun laying and fire control, bomb direction, and navigation. They are used in the air, on shipboard, and on the ground; in attack and in defense; in combat zones and in rear areas. To realize the advantages of different parts of the frequency spectrum, avoid interference, and keep ahead of enemy countermeasures, it has been necessary for radar to exploit many different frequency bands and sub-bands. These diversities have bred a multiplicity of types of radar, with a corresponding variety of testing problems and requirements.

Maintenance and testing of radar equipment must be performed at many different locations. In the Army these locations, known as echelons, include

1. The operating unit.
2. Central service points, either fixed or mobile, for a number of operating units.
3. Large depots either in the military theaters or in the United States.

Navy maintenance and testing are carried out aboard the fighting ships or auxiliaries and at advance and overhaul bases.

In developing test equipment, an offhand approach might have been to provide specialized equipment for testing each radar set under specific conditions. Since this would have made the total burden of development, manufacture, and field maintenance well-nigh intolerable, a co-ordinated plan was followed whereby (with minor exceptions) each test set was made capable of widespread application in testing as many radar equipments under as varied conditions as possible.

### Broadbanding

Generality of application required the designing of test equipment for broad frequency bands, bands as a rule much wider than those of the radar sets themselves. It was necessary, therefore, not only to develop new microwave testing techniques, but to advance the art still further to render the testing components as far as possible insensitive to frequency.

### Precision

A radar set itself is an instrument of considerable precision. The test equipment used for checking the radar performance in the field has to have still higher accuracy. It is noteworthy that the measuring accuracy realized throughout the microwave range is comparable with that obtainable at lower frequencies where many years of background exist.

### Packaging—Size and Weight

Light weight and compactness are of paramount importance where a test set

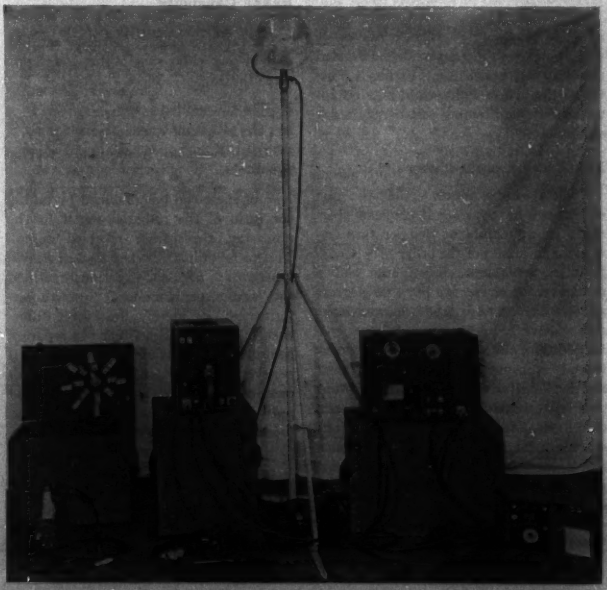


**Figure 2. Early radar test set for 3,000-megacycle range**

It includes signal generator, oscilloscope, power meter, test antenna, and auxiliary units

has to be carried any distance by the maintenance man; where it is used in cramped quarters in a plane, truck, or submarine; or where it has to be taken up ship ladders or through small hatchways. To permit portable use under such conditions, the design objective was established of a weight not exceeding about 30 pounds (exclusive of transit case), combined with a ruggedness adequate for all conditions of use. Through rigorous attention to both mechanical and electrical design, this objective has been realized (in many cases with considerable margin) except for a few sets intended primarily for bench use. Figure 3 illustrates the use of lightweight test equipment in maintaining air-borne radar equipment.

**Figure 3. Portable units used in checking air-borne radar sets at Boca Raton, Fla.**

### Environmental Influences

Military usage requires that the test equipment be capable of efficient operation at any ambient temperature between a minimun of the order of −40 degrees to −55 degrees centigrade and a maximum of the order of +65 degrees to +70 degrees centigrade, as well as at any relative humidity up to 95 per cent. In addition, the set must withstand continued exposure to driving rain, dust storms, and all other conditions encountered in tropical, desert, or arctic climates. Often the test set in its transit case must be capable of submergence under water without ill effects. Fungus-proofing with a fungicidal lacquer is a standard requirement.

### Simplicity, Reliability, Accessibility

Not only must the functioning of the test set be reliable, stable, and trouble-free, but the set must make minimum demands for special skill or technique on the part of the maintenance man. Access for maintenance purposes, while important in radar test sets, is not as controlling as in the radar equipments themselves and sometimes has to be sacrificed in part for compactness.

### Ruggedness

For general application, the test equipment must be capable of withstanding airplane vibration, the shock of heavy guns, depth charges and near misses, and the combinations of shock and vibration connoted by the requirement of "transportation over all types of terrain in any Army vehicle." Test and experience have made it possible to translate these general requirements into two specific requirements, namely, the ability to withstand

1. Vibration at frequencies from 10 to 33 cycles per second, with 1/16 inch excursion for 30 minutes in each of three axes.

2. The shock produced by a 400-pound hammer falling through distances of one, two, and three feet in each of three axes and striking an anvil to which the set is attached.

These requirements have been met without using shock and vibration mounts, which are undesirable in test sets because they increase size and weight.

## Range Capability

The range capability of a radar set, like that of any radio system, depends upon three things:

1. The transmitted power.
2. The loss in the medium.
3. The minimum perceptible received signal.

Two of these can be combined by taking the ratio of the radiated signal to the minimum perceptible received signal. This ratio, ordinarily expressed as a level difference in decibels, is variously termed the "system performance," "over-all performance," or merely the "level difference." It may be determined by separate measurement of transmitter power and receiver sensitivity, or by a single over-all measurement. With the powers and sensitivities commonly employed in radar, the level difference is of the order of 150 to 180 decibels.

The acttal range that can be spanned for a given performance ratio varies considerably. For a given transmitted power, the echo power received by a radar set theoretically varies inversely as the fourth power of the range. The reason for this is simple. In free space the power intercepted by a target which is small in comparison with the area of the radar beam in its vicinity will vary according to the inverse square of the distance from the radar. Similarly, that fraction of the energy reflected from the target which is intercepted by the receiving antenna will vary as the inverse square law. Since the received power involves the product of these two factors, the relation becomes

$$P_r = K\frac{P_t}{R^4} \text{ or } R = \left(K\frac{P_t}{P_r}\right)^{1/4} \qquad (1)$$

where $P_t$ and $P_r$ represent, respectively, the transmitted and received power; $R$, the range; and $K$, a constant determined by antenna design, character of target, and so forth.

Under operating conditions, considerable departure from the above relationship may be experienced, because of such factors as

1. The curvature of the earth.

2. Interference between the direct beam and single or multiple reflections.

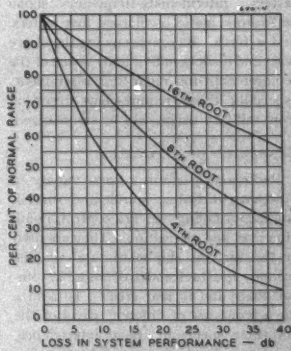



**Figure 4. Effect of reduction in system performance on radar range**

3. Attenuation caused by atmospheric absorption.

Except under conditions of severe attenuation such as may occur at the very short wave lengths, the received power commonly varies somewhere between the inverse fourth power and the inverse sixteenth power of distance. To state it another way, the change in effective range is somewhere between the fourth and the sixteenth root of the change in system performance. The former condition might hold for high-angle plane-to-ship search in

clear weather, the latter for ship-to-ship search in fog. The loss of range resulting from a given degradation of system performance is shown for fourth, eighth, and sixteenth root laws by the curves of Figure 4. Whatever the propagation law, reduction in performance always means loss of range.

Field surveys have shown that when test equipment is not available or not used, radar sets in the field are likely to give no more than one half to one fourth of the maximum range of which they are capable. Hence it is necessary to know with good accuracy the over-all performance. Known or so-called standard targets have often been used in the field for checking performance. Because of wide variations in transmission caused by many factors, results obtained from such targets are frequently misleading.

**Figure 6. 1942-model signal generator (left) compared with one produced in 1945**

## Signal Generators

Signal generators for radar work deliver one or more different types of test signals, which may serve a variety of functions. More important among these functions are

1. Tuning or alignment of the radar components (TR and RT boxes, converter, beat oscillator, automatic frequency control, and so forth).
2. Measurement of receiver sensitivity.
3. Check of TR and receiver recovery.
4. Measurement of loss.
5. Detection of frequency pulling.
6. Check of automatic frequency control following.
7. Measurement of intermediate-frequency band width.
8. Check of automatic range tracking.
9. Measurement of standing wave ratio.
10. Check of video "gating" circuits.

Many signal generators include means for measuring the power and frequency of the test signal and also of an incoming signal.

### Types of Signals

The test signals delivered by a signal generator may be continuous wave, pulsed, or frequency-modulated. Occasionally, square wave or sine wave modulation is provided.

Pulsed signal generators deliver a succession of single RF pulses or pulse trains, either of these generally synchronous with the pulses of the radar equipment under test. Multivibrator or trigger techniques are used to generate the pulses for modulating the microwave generator. The trigger pulse for synchronizing the pulsing circuits is commonly produced by rectifying RF pulses from the radar transmitter, thus avoiding a separate video connection to the radar. To avoid possible difficulties in video response, the RF test pulses should be of a width comparable with those of the radar set under test. For observing the test signals, either the radar indicator or an auxiliary oscilloscope may be used. With the single pulse method, provision is usually made for varying the delay of the test pulse with respect to the radar pulse. The width of the test pulse may also be adjustable or variable.

If the frequency of the signal generator is swept over a sufficiently wide frequency band, the IF output of the radar set traces the curve of IF selectivity, thus producing a kind of pulse. With a suitable rate of frequency sweep, this pulse becomes comparable in width with the transmitter pulse, and when synchronized with the radar set it can be used for test purposes. Since the pulse is produced in the radar equipment, comparison of the shapes of receiver input and output pulses is not possible. The nominal duration of the pulse in the IF output is

$$T = B/\gamma \qquad (2)$$

where $B$ is the width of the IF band in cycles per second (for this purpose conveniently measured between six decibel points) and $\gamma$ is the speed of frequency sweep in cycles per second per second. For best results this nominal width should be similar to the width of the transmitter pulse for which the IF and video circuits are designed. This means that the scanning speed should be in the neighborhood of $B^2/2$.

A continuous-wave input of the same frequency as the transmitter produces in the output of the IF detector merely a direct current to which the video amplifier and radar indicator do not respond. However, continuous-wave test signals may be utilized by observing on a d-c meter (built into the radar set or separate) the change produced in detector current or converter current.

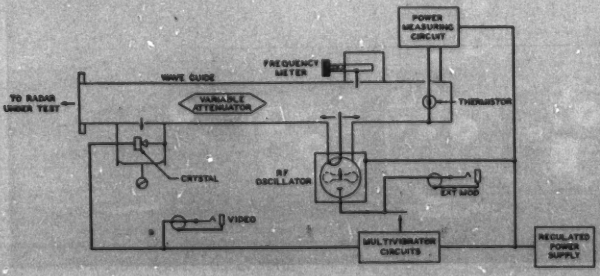



**Figure 5. Block diagram of TS-35A/AP signal generator**

### Receiver Sensitivity

Just as in radio, the sensitivity of a radar receiver is defined as the minimum received signal that is perceptible in the presence of set noise.* At microwave frequencies, atmospheric disturbances are usually negligible, so that unless accidental or deliberate interfering signals are present, the operating sensitivity is the same as the intrinsic sensitivity of the receiver.

Receiver sensitivity is commonly stated as the minimum perceptible signal power in decibels referred to a milliwatt (abbreviated as dbm). In practice, the receiver

*The term noise is commonly used even though the disturbances are observed on a cathode-ray screen.

sensitivity depends upon the noise figure of the converter, the conversion loss, and the noise figure of the IF amplifier. If a RF amplifier is used, as is the practice at lower microwave frequencies, its noise figure is likely to be controlling. By noise figure in each case is meant the noise power in comparison with the thermal noise. The thermal noise in watts delivered to a load is $kTB$, where $k$ is Boltzmann's constant, $T$ is absolute temperature in degrees $K$, and $B$ is the frequency band width. Thus for a 4-megacycle band at 25 degrees centigrade, the thermal noise is $-108$ decibel-milliwatts. With good design the over-all receiver noise is of the order of 10 to 15 decibels higher than thermal noise. The minimum detectable signal is usually not equal to the receiver noise but depends on the type of indicator, particularly on whether the presence of an echo is indicated by spot deflection or spot modulation.

With a continuous-wave signal generator, receiver sensitivity is measured by determining the minimum input power necessary to produce a perceptible change in meter reading. This affords a satisfactory relative measure of receiver performance, but since the radar indicator usually permits better visual discrimination against noise, the minimum input as read with the meter ordinarily differs from the minimum pulse input for barely discernible indicator response.

### Radio-Frequency Oscillators

Beat oscillator tubes for radar sets deliver (with sufficient decoupling or isolation to prevent undue frequency pulling) a power of the order of milliwatts. This power being adequate for most test purposes, such tubes are well adapted for use as signal generators.

Throughout the greater part of the microwave range, reflex velocity-modulated tubes,[2] both the type with built-in cavity (Pierce-Shepherd) tuned mechanically or thermally, and that with external cavity (McNally) tuned by plugs, vanes, or adjustment of dimensions, have been used. The former is more convenient for general use, but the latter usually permits wider frequency coverage. Oscillation occurs when the repeller voltage is adjusted so that the round trip transit time corresponds to an odd number of quarter wave lengths. Ordinarily there are several different ranges of repeller voltage,

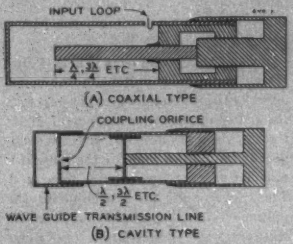



**Figure 7. Types of frequency meters**

corresponding to different numbers of quarter waves, each of which supports oscillation over a range of frequencies called a mode of oscillation. Pulsing or frequency modulation is accomplished by applying a pulse or sawtooth wave to the repeller.

At the longer microwaves, a triode with closely spaced electrodes, or so-called "lighthouse" tube,[3] has been employed in a tuned-plate tuned-grid oscillator of the positive grid type. Two coaxial lines, conveniently placed one inside the other, provide the tuning, with the feedback through interelectrode capacitances supplemented by loop coupling. The inner cavity (between plate and grid) controls the frequency of oscillation, while the outer cavity (between grid and cathode) provides a suitably high grid impedance. Mechanical arrangements are provided for tracking the tuning of the two cavities over a wide frequency range.

### Some Design Principles

Standard signal generators which have been employed in the past for measuring the sensitivity of radio receivers usually deliver a known voltage across a low impedance. This voltage is applied in series with a dummy antenna to the receiver under test. In the microwave range, this technique is inconvenient, and signal generators are designed to deliver test power on a matched impedance basis. Receiver sensitivity is stated in terms of power (decibel-milliwatts) instead of volts.

The components of a signal generator or other test unit are commonly arranged along a microwave transmission line. The wave guide type of line possesses certain advantages over a coaxial line in affording a lower loss, facilitating attenuator design as discussed in a subsequent section, and so forth. Hence the wave guide type of line is used in test equipment for those frequencies where its size is not excessive, that is, from about 4,000 megacycles upwards, and coaxial line for lower frequencies.

A major problem in the design of microwave signal generators is the provision of shielding adequate to reduce leakage signals, caused by unwanted couplings or stray fields, well below the minimum signal required for receiver testing. This minimum level may be as low as $-70$ or

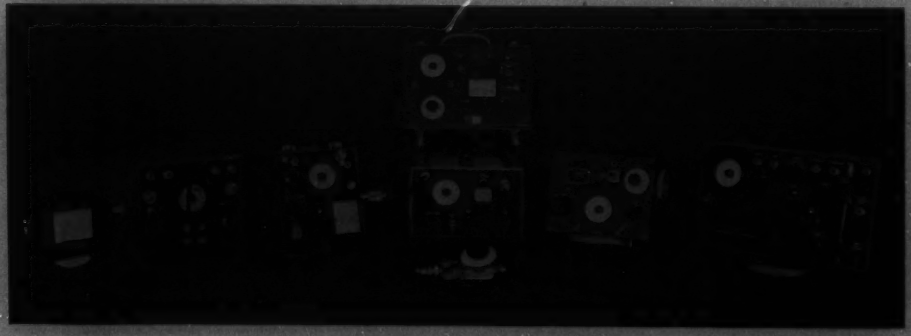


**Figure 8. A group of frequency and power meters designed for various bands in the frequency range from 500 to 25,000 megacycles**

80 decibel-milliwatts depending on the coupling loss in the test connection.

### Pulsed and Frequency-Modulated Signal Generator

To illustrate the functioning of a signal generator, there is shown in Figure 5 a block schematic of a design (Army-Navy type *TS-35A/AP*) which covers a 12% frequency band in the vicinity of 9,000 megacycles. An RF connection to the radar equipment is established with a wave guide flange coupling. The frequency and power of the radar transmitter are measured by means of a coaxial-type frequency meter and thermistor power-measuring circuit as described in subsequent sections. The attenuator and pad are adjusted to reduce the incoming average power to about one milliwatt, which gives a suitable deflection on the indicating meter. The

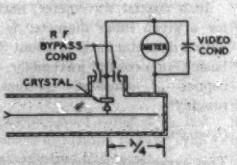



**Figure 9. Crystal detector for pulsed RF signals**

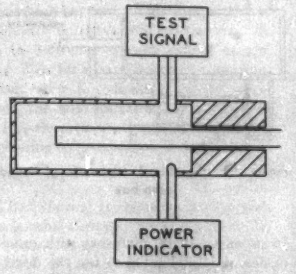
thermistor is mounted across the wave guide.

An RF pulse train is employed in many tests. To produce this, the RF oscillator output is modulated by a multivibrator which pulses continuously except when being synchronized. Synchronizing pulses are derived by crystal rectification of the RF pulses from the radar transmitter. The result is an initial RF pulse of seven microseconds, followed by an off period of about ten microseconds, followed by a train of RF pulses each two microseconds wide and recurring every eight microseconds until resynchronization occurs at the next radar pulse.

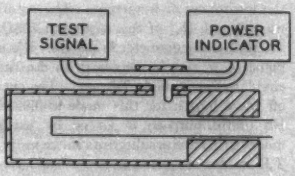
Using the pulse train, the radar system components can be tuned for maximum sensitivity by maximizing the signal on the indicator. To check receiver sensitivity, the continuous-wave power is first adjusted so that a power of one milliwatt is delivered to the pad and attenuator. Then with the set in the pulsed condition, the amplitude of the test signal is adjusted by means of the attenuator and pad until the signal on the radar indicator is barely discernible. It is necessary for this test that the frequency of the test signal be equal to the magnetron frequency. The frequency meter is provided as part of the signal generator for this purpose.

The receiver recovery, that is, the time required by the receiver to recover after disablement by the transmitter pulse, determines the minimum range at which a radar can be used. With this test set, the receiver recovery characteristic is indicated by the amplitude of the test pulses in the interval immediately following the transmitter pulse.

The set also is adapted to serve as a frequency-modulated signal generator. A sawtooth wave applied to the repeller gives a succession of frequency sweeps, each about 20 megacycles wide, and lasting about six microseconds. With this frequency-modulated signal, the width of receiver response may be observed on a class A oscilloscope, that is, one showing signal amplitude versus time. However,




a. TRANSMISSION TYPE




b. REACTION TYPE

**Figure 10 (above). Types of frequency meter circuits**

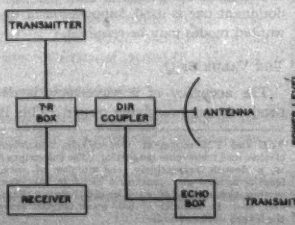
with nonadjustable intermediate-frequency strips, such measurement is seldom required. Failure of the radar automatic frequency control to follow frequency changes caused by antenna scanning or other causes is indicated by a change in the indicator presentation. Pulling of the magnetron frequency because of changes in load impedance can be detected by turning off the automatic frequency control.

### Signal Generator Designs

Designs of signal generators developed for the military arms during the war are interesting as landmarks of progress. The signal generator of the *IE30* test set, deliveries of which began in May 1942, delivered pulsed RF signals in the ten-centimeter range, using sine wave synchronization. Following only three months later was the signal generator of the Army *IE57A* and the Navy *LZ* test sets (Figure 6), which covered a then very broad frequency band of 20 per cent in the vicinity of ten centimeters and was designed to be triggered by the incoming RF pulse from the radar set instead of by a separate synchronizing connection. This set and a redesigned version of it have seen wide usage in testing Army, Navy, and Marine Corps radar equipment.

Delivery of a test set for the three-centimeter range, designated *TS-35/AP*, started in the fall of 1943. This set furnished both a train of pulses and a train of frequency-modulated signals, both of which features have proved valuable. It covered a nine per cent frequency band with no tuning adjustment except for the oscillator. An improved design known as *TS-35A* (see Figure 6) covered a 12 per cent band.

Progress in reducing the size and weight of the test units is indicated by the fact that the *IE30* signal generator weighed 121 pounds and *IE57* weighed 74 pounds, whereas *TS-35* and *TS-35A* weigh approximately 30 pounds.



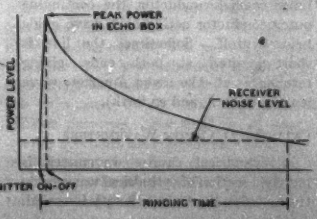
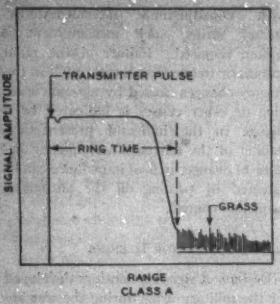
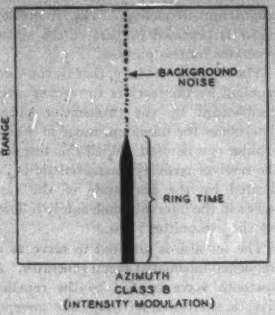




**Figure 11 (below). Radar test with echo box**



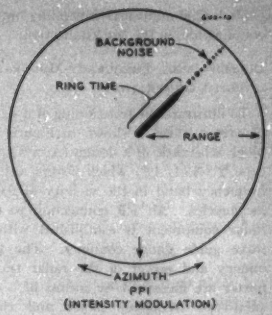




**Figure 12. Typical ringtime patterns on radar indicators**

## Frequency Measurement

Usually a radar set need not operate at a precise frequency. Accurate measurements are required in the field, however, to keep the operating frequency within limits, to set the local oscillator, to check the measuring frequency, and so forth. In the laboratory, accurate frequency measurement is fundamental.

Frequency measurement in the microwave range is ordinarily accomplished by

1. A resonant coaxial line or
2. A resonant cavity, generally cylindrical.

These types are illustrated in Figure 7. Sometimes a combination of the two, referred to as a hybrid or transition type resonator, is employed. The measurement is actually one of wave length, with the scale calibrated in frequency or a conversion chart provided. Some specific designs of frequency meters are shown in Figure 8.

### Coaxial Wavemeters

A coaxial wavemeter is formed of a section of coaxial transmission line of small enough diameter so that only the coaxial mode (in wave guide notation, $TM_{0,0,n}$) can exist. Usually the line is short-circuited at one end and open at the other, in which case resonance occurs at the odd quarter wave lengths ($\lambda/4$, $3\lambda/4$, and so forth). The open circuit is obtained merely by terminating the inner coaxial conductor, the continuing outer conductor acting as a wave guide below cutoff. Sometimes the line is short-circuited at both ends, giving resonance at the even quarter wave lengths ($\lambda/2$, $\lambda$, and so forth).

### Cylindrical Cavity Wavemeters

A cylindrical cavity wavemeter is merely a section of cylindrical wave guide transmission line[4] whose length is varied.

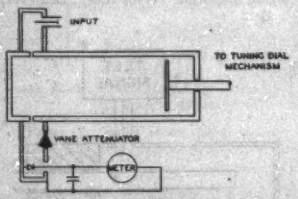



**Figure 13. Functional schematic of tuned echo box**

In order to avoid confusion with other modes, it is preferable to use the dominant mode (described in wave guide notation, $TE_{1,1,n}$*), that is, the mode with the lowest cutoff frequency. The cutoff wave length ($\lambda_c$) of this mode is $1.706D$, where $D$ is the diameter in meters. For a higher $Q$ it may be necessary to use the circular electric mode $TE_{0,1,n}$. The cutoff wave length for this mode is $0.82D$. No useful purpose is served by using modes with $l$ and $m$ subscripts above unity. $TM$ modes are often used for fixed frequency cavities, but for variable cavities $TE$ modes are preferable since these have zero current at the inner wall of the cylinder and thus obviate moving-contact difficulty. If any mode higher than the dominant one is used, suppression of unwanted modes may be required.

### The Value of $Q$

The accuracy of a wavemeter is dependent on its resolving power. This in turn depends upon $Q$, which is an index of the decrement of the resonant circuit and is equal to $f/\Delta f$, where $\Delta f$ is the distance between three decibel points on the resonance curve.

In a coaxial wavemeter, maximum $Q$ for a given inner diameter is obtained with a diameter ratio of about 3.6.[5] The basic $Q$ of a coaxial wavemeter, assuming copper of standard conductivity, is roughly[4]

$$Q_0 = 0.042D\sqrt{f} \qquad (3)$$

This expression neglects end effects and hence gives somewhat too high a value of $Q$.

The basic $Q$'s for $TE_{1,1,n}$ and $TE_{0,1,n}$ cylindrical cavity resonators employing copper of standard conductivity are, respectively,

$$Q_0 = 0.0937\times10^{10}\frac{A^3}{\sqrt{f}}\times\frac{1}{1+B^3\left(0.826\frac{B}{n}+0.295\right)} \qquad (4)$$

$$Q_0 = 0.2762\times10^{10}\frac{A^3}{\sqrt{f}}\times\frac{1}{1+B^3\left(2.439\frac{B}{n}\right)} \qquad (5)$$

where $A = \lambda_c/\lambda$, $B^3 = A^3 - 1$, and $f$ is in cycles per second.

The value of $Q$ which determines accuracy is not the basic $Q$, but the loaded or working $Q$, herein designated $Q_L$.

The resolving power of a wavemeter used for measuring a single frequency can be made considerably better than $f/Q_L$. With a sensitive meter it is readily possible to detect differences less than one decibel, which corresponds to a frequency interval of $f/2Q_L$.

The required accuracy in a wavemeter is generally absolute rather than a percentage. Hence increasingly large values

*$TE$ and $TM$ represent, respectively, transverse electric and transverse magnetic. The subscripts $l$, $m$, $n$ denote, respectively, the number of wave lengths around any concentric circle in the cross section, the number of wave lengths across a diameter, and the number of half wave lengths along the length of the cylinder.

Figure 14. A group of echo boxes of various types

of $Q_L$ are required at the higher frequencies. Thus for a resolution of one megacycle, assuming one decibel discrimination, the values of $Q_L$ required for different frequencies are:

| Frequency | $Q_L$ | Frequency | $Q_L$ |
|---|---|---|---|
| 1,000 mc | 500 | 10,000 mc | 5,000 |
| 3,000 mc | 1,500 | 25,000 mc | 12,500 |

An unnecessarily high value of $Q_L$ has the disadvantage of making it more difficult to find the desired frequency.

### Linearity

The displacement of the coaxial plunger of a coaxial-type wavemeter for resonance is substantially a direct linear function of free space wave length, and if an ordinary centimeter micrometer drive is used, it is possible to read wave length differentials directly. Over band widths less than 20 per cent, displacement versus frequency is also quite linear, which is of considerable advantage for some uses.

For the cavity-type wavemeter, the displacement is a variable function of free space wave length and becomes very nonlinear as the cutoff frequency of the guide or cavity is approached. This is evident from the relation between wave length in the guide, $\lambda_g$, wave length in free space, $\lambda$, and cutoff wave length, $\lambda_c$:

$$\lambda_g = \frac{\lambda}{\sqrt{1-\frac{\lambda^2}{\lambda_c^2}}} \qquad (6)$$

A cam or mechanical linkage may be employed to obtain a linear scale.

### Frequency Coverage

Increasing the length of a wavemeter is desirable because this gives a larger mechanical displacement for a given frequency interval. The permissible increase is limited, however, by ambiguity with the next lower mode in going toward the upper end of the frequency scale and with the next higher mode in going toward the lower end. This means that if ambiguity is to be avoided, the ratio of top to bottom frequency cannot exceed $(n + 2)/n$ for a coaxial line of $n$ quarter-waves. For a cylindrical cavity resonator, the ratio for the 0, 1, $n$ mode must be less than $(n + 1)/n$, the exact limit depending on proximity to cutoff.

### Guideposts

The following guideposts are suggested for choosing the type of wavemeter in the microwave range. Where limitations of size and $Q$ permit, the coaxial quarter-wave type should be used because of its greater linearity. If this type is inapplicable, the cavity type with $TE_{1,1,n}$ should be used unless its $Q$ is inadequate, in which case $TE_{n,1,n}$ should be employed.

### Couplings

A loop, orifice, or probe may be used for coupling to a wavemeter. Coupling to a coaxial wavemeter is generally effected by a loop placed near a short-circuited end so as to be in the maximum magnetic field. For coupling to a cylindrical cavity wavemeter, an orifice in or near the base of the cavity is usually employed. The coupling to the wavemeter is kept small enough to avoid serious reduction of loaded $Q$.

### Types of Detectors

Various types of detectors may be associated with a wavemeter, the most commonly used being (1) a crystal rectifier and microammeter and (2) a thermistor bolometer. When a crystal rectifier is employed with a cavity or coaxial wavemeter, a circuit similar to that shown in Figure 9 is used. Important items in such a circuit are the RF by-pass capacitor, and the video capacitor. The latter, by providing a low impedance path to the video signals, improves rectification efficiency when the input signal is pulsed. The quarter-wave stub shown in the figure is used when the input or coupling circuit does not provide d-c and video paths. When the signal is pulsed at a low-duty cycle, high peak currents through the crystal are obtained even though the average current through the meter is small, and it is possible to impair or burn out the crystal unless extreme care is taken. The use of a thermistor, which is self-protecting for large overloads, avoids this danger. Another expedient is to limit the crystal current to a small value and employ a video amplifier and oscilloscope.

### Methods of Use

A wavemeter may be used as either a transmission or a reaction instrument. In the former case (Figure 10A), it is inserted directly in the transmission path, so that substantially no through transmission occurs except at resonance. In the latter case (Figure 10B), the wavemeter is coupled to the transmission path or a branch circuit. When the meter is tuned off resonance, it presents such a high impedance to the main path that its effect is negligible. At resonance, however, it offers a lower impedance which reflects energy in the main line so that less power reaches the detector and a dip in the reading occurs. For most applications the reaction arrangement is preferable, since the power transmitted when the wavemeter is off tune may serve various purposes. For analysis of frequency spectrum the transmission method is necessary. This method requires two couplings to the wavemeter, which lowers the $Q$ as compared with the reaction type.

### Drive and Scale

A direct drive with a precision lead screw of the micrometer type is frequently used. Accuracy of reading is insured by spring loading to minimize backlash and by specifying close tolerances for threads and for concentricity of plunger and cavity. The scale on a wavemeter must be fine enough to permit utilization of the resolving power. The conventional micrometer type of scale sometimes makes accurate reading difficult in a small compact meter. Scale mechanisms which have been used include counter types, clock face, or expanded drum types with gearing between vernier and coarse scales, and a single direct reading scale with divisions arranged in a spiral for compactness.

### Effect of Temperature and Humidity

To minimize the effects of temperature on the accuracy of readings, invar has been employed for elements whose dimensions affect the wave length. For accurate work, the scale reading must be corrected for temperature. A rough approximation is that the scale reading varies in accordance with the coefficient of expansion of the metal.

Water vapor included in the air dielectric of a wavemeter has an appreciable effect on the dielectric constant and hence on the resonant frequency.[7] Thus, for example, in going at sea level from 25 degrees centigrade and 60 per cent humidity to 50 degrees centigrade and 90 per cent humidity, the scale reading should be reduced by 0.03 per cent. Correction can be made by means of a chart, a convenient form of which has been prepared by Radiation Laboratory.

### Calibration

Frequency meters are calibrated against sub-standards which in turn are calibrated against a multiplier from lower frequencies for which a high order of accuracy can be obtained. Such multipliers have been made available at Radiation Laboratory and the National Bureau of Standards. The accuracy obtained at interpolation frequencies is of course less than at exact multiples of the base frequency. In the microwave range, the accuracy is believed to be of the order of one part in 100,000.

## Power Measurement

There are two needs for power measurement in radar maintenance, namely, in evaluating transmitter performance and in standardizing test signals. Power output is, of course, only one factor in transmitter performance, others being (a) frequency and (b) spectral distribution or shape of RF envelope. Ability to measure absolute power is desirable to permit interchangeable use of sets in the field.

### Measurement of Pulse Power

The transmitter power as used in formula 1 is the average power during the pulse. The relationship of pulse to (long) average power is

$$\frac{P_t \text{ avg}}{P_t \text{ pulse}} = Tf_r \qquad (7)$$

$T$ is the pulse duration in seconds and $f_r$ is the pulse recurrence frequency (P.R.F.) in cycles per second. The product $Tf_r$ is the duty cycle. (Sometimes the reciprocal of this number is referred to as the duty cycle. The magnitude is usually such that no ambiguity arises.)

During the early days of radar, it was the practice to measure pulse power. The test equipment was coupled to the radar set by a path of known loss. The RF envelope was derived by means of a crystal rectifier and applied to an oscilloscope. With the aid of an RF attenuator, the level applied to the crystal rectifier and oscilloscope was held constant. Calibration was obtained by using a signal generator whose output was standardized, prior to pulsing, with an averaging type of power meter. The procedure was rather involved, with several sources of possible error. Since it is much simpler to measure average power, field measurement of pulse power soon was abandoned. Though the pulse power can be computed from average power if the pulse width, pulse shape, and repetition rate are known, it soon became the practice to specify field performance requirements in terms of average power.

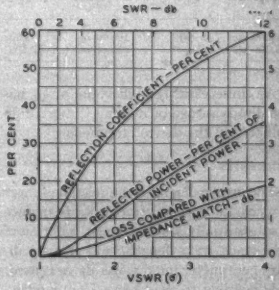

SWR — db
0 2 4 6 8 10 12
PER CENT
DECIBELS
REFLECTION COEFFICIENT — PER CENT
REFLECTED POWER — PER CENT OF INCIDENT POWER
LOSS COMPARED WITH IMPEDANCE MATCH — db
VSWR (σ)
1 2 3 4

**Figure 16. Relations in mismatched transmission lines**

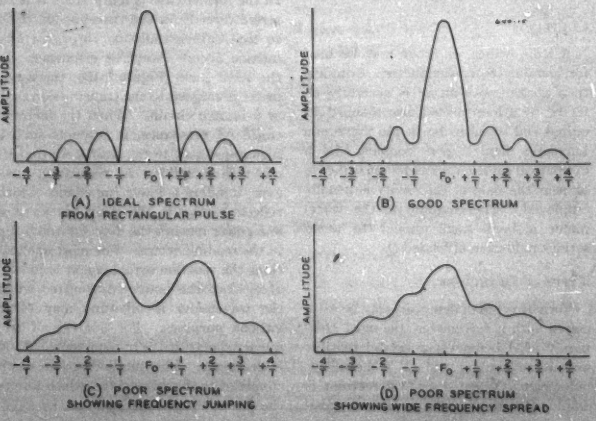

AMPLITUDE
(A) IDEAL SPECTRUM FROM RECTANGULAR PULSE
(B) GOOD SPECTRUM
(C) POOR SPECTRUM SHOWING FREQUENCY JUMPING
(D) POOR SPECTRUM SHOWING WIDE FREQUENCY SPREAD

**Figure 15. Radar spectrum analysis with echo box**

### Thermistor Power Meters

A number of devices have been used for measuring average power in the microwave range. Those suitable for handling the small amounts of power normally involved in field tests include thermistors, platinum wires, and thermocouples. In each case the RF power to be measured is absorbed in the measuring element. The measurement consists in observing the resistance change in the thermistor or platinum wire, or the thermoelectric voltage from the thermocouple. By analogy with devices used for measuring minute quantities of radiant heat, either a therm-

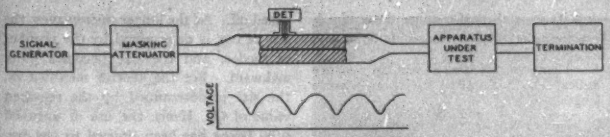



Figure 17. Standing wave measurement

Figure 18. Standing wave detectors used on coaxial and wave guide transmission lines

istor or a platinum wire instrument is sometimes referred to as a bolometer. The platinum wire device has also been termed a barretter.

A thermistor for microwave power measurement is a tiny bead (about five mils in diameter) composed of a mixture of oxides of manganese, cobalt, nickel, and copper, constituting a resistor with a very high negative temperature coefficient.[8]

The thermistor has a number of advantages for microwave work, namely:

1. Resistance is highly sensitive to change of heating power, which obviates any need for amplification or a super-sensitive meter and makes it possible to use a rugged d-c meter.

2. Reactance is low compared with RF resistance, which makes it possible to incorporate the thermistor in a power-absorbing termination which matches the impedance of a microwave transmission line over a wide band.

3. Resistance change is the same function of electrical heating power at any frequency, which permits direct comparison of the unknown microwave power with easily measurable d-c power.

4. Sensitivity to damage and burn-out is inherently low, and added protection results from impedance mismatch during overload.

Because of these characteristics, thermistors have been far more widely used than other detectors for microwave power measurement. Broadband thermistor mounts have been designed to match both wave guide and coaxial transmission lines, the latter not only in the microwave range but also down to low frequencies. Some of the test sets specifically intended for power measurement or for combined power and frequency measurement are shown in Figure 8.

The change in the thermistor resistance caused by radio-frequency heating current is determined by placing the thermistor in one arm of a d-c bridge. By noting the d-c power necessary to balance the bridge with and without RF power in the thermistor, the magnitude of the RF power may be determined. For most purposes, however, a direct-reading power meter is preferable. This can be obtained over a moderate range of power levels by employing an unbalanced bridge. The bridge is balanced for direct current only, and the measurement consists in noting the meter deflection when radio-frequency power is added.

The resistance of a thermistor is a highly sensitive function not only of electrical heating power but also of ambient temperature. For convenient field measurement, the effect of ambient temperature must be cancelled out in the indicator circuit so that the indication depends only on RF power.

### Water Loads

A method which has been used in the laboratory and the factory for measuring high level microwave power consists in terminating the RF transmission line in a water load arranged as a continuous flow calorimeter. This method can be made quite accurate but is cumbersome. More recent practice is to terminate the RF line in a solid load of a type described later in this article and to couple a thermistor power meter to the line by means of a directional coupler (described below) of known loss. Very close correlations have been obtained between the two methods over the entire microwave band.

## Echo Boxes

A device unique to radar testing is a high $Q$ resonant cavity, known as an echo box or ring box. The cavity is coupled to the radar transmission line or antenna as indicated in Figure 11. During the transmitted pulse, microwave energy is stored in the cavity. In the period immediately thereafter, energy is returned to the radar over the same path, producing a signal on the radar indicator. The energy in the cavity builds up exponentially to an amplitude dependent on the radar power. At the end of the pulse, the returned energy decays exponentially, disappearing into the noise at a point determined by receiver sensitivity. The time interval between the end of the transmitted pulse and the point where the signal on the radar indicator disappears into the background noise, called the ringtime, therefore measures the over-all performance of the radar set.

An echo box is a particularly useful instrument for radar testing because

1. It measures over-all performance directly

2. It permits a rapid tune-up.

3. It utilizes the radar transmitter as its only source of power and therefore can be made extremely portable.

Figure 12 shows typical ringtime patterns on different types of indicators. In actual practice the ringtime is read in miles on the radar range scale and hence is measured from the beginning of the transmitted pulse rather than the end. The difference is unimportant, however, since standard and limiting values of ringtime are established for operating conditions. It will be noted that the echo box does not return a true echo to the radar, so that the name "echo box" is not entirely appropriate.

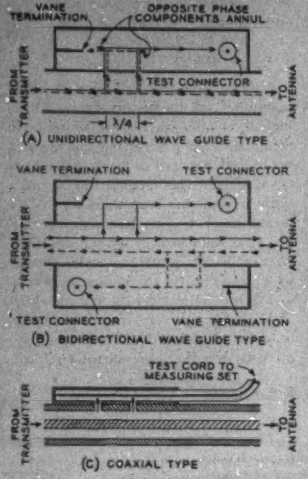



**Figure 19. Directional coupler arrangement**

### Types and Uses

Echo boxes are of two general types, tuned and untuned. A tuned echo box is designed to resonate in a single mode adjustable over the operating frequency range. An untuned echo box is a fixed cavity of a size sufficient to support a very large number of modes within the working range. Tuned echo boxes are more versatile and more widely used than untuned boxes.

The most common type of tuned echo box is designed for hand tuning. While other shapes are possible, the most convenient one is a right cylinder whose length is adjusted by a movable piston. The $TE_{0,1,n}$ mode gives maximum $Q$ for a given volume and minimizes the number of unwanted modes present within the desired band. The value of $n$ is determined by the desired value of $Q$ (see formula 5). Unwanted modes can be partially avoided by choice of design parameters. However, for high values of $Q$, and especially for broad frequency bands, the suppression of unwanted modes involves design problems of the highest order.

As indicated in Figure 13, a tuned echo box cavity is usually provided with two couplings. One of these is to the radar pick-up; the other is to an attenuating device, crystal rectifier, and meter, which serve for tuning the cavity and for other purposes. With such an instrument, not only can the radar be tuned up and its over-all performance determined, but many other tests can be made, to wit:

1. The setting of the plunger at resonance indicates the transmitter frequency or wave length.

2. Calibration of the crystal affords a rough measure of output power.

3. Since the $Q$ required for adequate ringtime is so high that the cavity selects only a narrow segment of the transmitter spectrum, a spectrum analysis can be made by plotting frequency versus crystal current reading.

4. Slow recovery of TR box and receiver after the transmitted pulse can be detected by noting the behavior of the ringtime pattern at short ranges as the echo box is detuned.

5. Inability of the receiver to recover promptly after a strong signal (the result of imperfect d-c reinsertion in the video amplifier or of overloading of the IF amplifier) is indicated by a blank following the end of the ring.

6. Improper pulsing (for example, double moding or misfiring) can be determined with a class A oscilloscope.

7. The frequency and power of the local oscillator can be measured.

In tuned echo boxes, requirements for extreme fineness of tuning control and precise resettability have given rise to interesting problems in the design of the mechanical drive and indicating mechanism.

In another type of echo box, hand tuning is supplemented by motor-driven tuning or so-called "wobbling" over a frequency range wide enough to embrace expected variations in transmitter frequency. Operation is controlled by a single push-button which energizes the motor and actuates the cavity coupling. Such an instrument may be permanently installed in a plane and used to check the radar during flight.

For an untuned or multiresonant echo box, rectangular shape is convenient. The box should be large enough to make it highly probable that over the operating band, one or more modes will be present within any frequency interval of width equal to the main concentration of the transmitter spectrum. For a given rectangular volume, a cube gives the largest number of modes. The total number of modes up to a frequency of wave length $\lambda_0$ is

$$N_M = 8.38V/\lambda_0^3 \qquad (8)$$

where $V$ is the volume. However, because of the cubical shape, many different modes tend to coincide in wave length, a condition referred to as degeneracy. To spread out the modes, the box is made slightly off cube and one or more corners sliced off. At the longer microwaves, the size of box is determined by the number of modes, and the size becomes quite awkward. For the shorter microwaves, the size is determined by the required value of $Q$. Hence the use of untuned echo boxes has been limited to the frequency range from about 9,000 megacycles upwards, with sizes of the order of from 12 to 24 inches on a side. Even with an extraordinarily high probability of finding modes within the radar band, substantial differences in response are found for relatively small changes in frequency. Accordingly, untuned echo boxes are more useful for rough tune-up than for precise measurement.

A number of specific designs of echo boxes for different microwave bands are shown in Figure 14.

### $Q$ and Ringtime

For satisfactory measurement the ringtime must extend beyond nearby echoes which would obscure the test signal. For most radars a ringtime of 20 to 30 microseconds (about two to three miles) has been found satisfactory, although considerably higher values have sometimes been provided. Even apart from echoes, a long ringtime is desirable since this gives a lower decay rate and a more sensitive measurement.

Computation will show that an extremely high value of $Q$ is necessary to obtain the desired ringtime. For maximum ringtime the cavity coupling should be such as to make the working $Q$ ($Q_L$) about 90 per cent of the nonloaded $Q$. Values of working $Q$ which have been provided in different frequency ranges are approximately as follows:

| Frequency | $Q_L$ | Frequency | $Q_L$ |
|---|---|---|---|
| 1,000 mc | 70,000* | 10,000 mc | 100,000 |
| 3,000 mc | 40,000 | 34,000 mc | 300,000 |

*In this case a higher $Q$ was needed for a long range ground search system.

The difference in performance corresponding to a given change in ringtime can be determined from the decay rate, which is

$$d = 27.3f/Q_L \text{ decibels per microsecond} \qquad (9)$$

For a given frequency, the ringtime is directly proportional, and the decay rate inversely proportional, to $Q$. For a given ringtime, the required $Q$ is directly proportional to frequency.

Accurate measurement of extremely high $Q$'s is essential in echo box work. A decrement method, in which a pulsed radio-frequency oscillator and oscillo-

scope are used to determine the loss corresponding to a known time interval, has proved most satisfactory.

## Spectrum Analysis

The frequency components of a non-repetitive rectangular d-c pulse may be determined by well-known methods using Fourier integral analysis. The envelope of amplitudes is of the form $(\sin x)/x$, where $x = \pi fT$. This envelope is shown by the right-hand side of the curve of Figure 15a, $f_0$ being assumed to represent zero frequency. The first zero occurs at the frequency $f = 1/T$.

Similarly, the envelope of the spectrum of a rectangular a-c pulse is given by the complete curve of Figure 15A, $f_0$ in this case being the carrier frequency. For a non-repetitive pulse, all frequencies are present in amplitude as shown by the envelope. When a stable carrier frequency is pulsed at uniform intervals and in precise phase relation, only harmonics of the repetition frequency are present under the envelope. In radar practice, conditions are, as a rule, not sufficiently stable for this to occur.

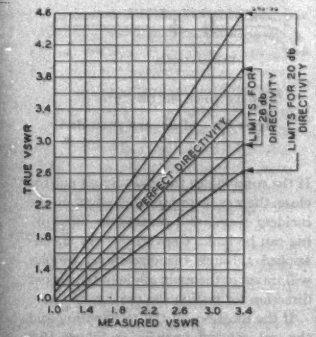



**Figure 20. Error in standing wave measurements caused by directivity of directional coupler**

Because of its band width, an echo box cannot reproduce the ideal spectrum envelope of Figure 15A. Instead, the curve for a good spectrum may resemble that of Figure 15B, while spectrum irregularities detrimental to radar performance may be revealed by curves such as those of Figure 15C and 15D. Broadening of the spectrum is undesirable because less energy falls within the receiver band. Energy removed from the main concentration may result from double moding

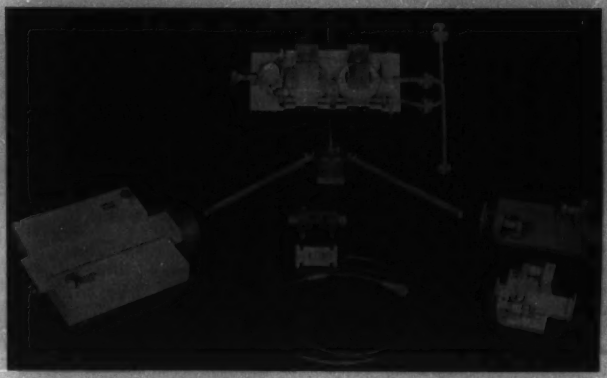


**Figure 21. A group of microwave directional couplers together with a directional coupler test set**

or from the occurrence of a different frequency during the rise or fall of the pulse. Frequency modulation caused by a sloping or spiked input pulse produces a non-symmetrical spectrum, not infrequently characterized by a high side lobe. Frequency jump in the middle of the pulse, resulting from line reflection, may produce two distinct maxima.

## Standing Wave Measurements

The expression for the distribution of current or voltage along a misterminated line of appreciable electrical length yields two terms which may be considered as representing two waves transmitted in opposite directions, one (the incident wave) from the generator toward the load, the other (the reflected wave) from the load toward the generator. The summation is a standing wave pattern. The standing wave ratio (SWR) is defined as the ratio of the wave amplitude at a maximum point (anti-node) to that at a minimum point (node). If the standing wave ratio is stated as a numeric, it is necessary to specify whether it applies to voltage (VSWR) or power (PSWR). Possibility of ambiguity is avoided by stating the ratio in decibels.

The ratio of the reflected current to the incident current is the reflection coefficient, here designated as $\rho$. The value of the reflection coefficient is given both in magnitude and phase by

$$\rho = \frac{Z_0 - Z}{Z_0 + Z} \qquad (10)$$

where $Z_0$ is the characteristic impedance of the line and $Z$ is the load impedance. The reflection coefficient is related to the standing wave ratio as follows:

$$\text{VSWR} = \sigma = \frac{1+\rho}{1-\rho}, \text{ or, } \rho = \frac{\sigma - 1}{\sigma + 1} \qquad (11)$$

Plots of the relationships are shown in Figure 16.

The reduction of radiated power because of reflection losses in a radar transmission line, while important, is usually less serious than other effects of impedance irregularities. Since the load impedance reacts on the oscillator circuit, the frequency and the output of most transmitter tubes are quite sensitive to load impedance. If the line is electrically long, so that its impedance varies rapidly with frequency, marked instability of oscillator frequency may occur, a condition referred to as "long line effect."

Since radar transmission lines contain many potential sources of impedance discontinuity, including not only the antenna but a variety of couplings, bends, wobble joints, rotating joints, switches, and so forth, measurements of standing wave ratio are frequently required. The need for such measurements depends in part on whether the line is "preplumbed" or is provided with field adjustments.

### Devices

Standing waves may be detected and measured by several different types of devices, including

1. A slotted line.
2. A squeeze section.
3. A directional coupler.
4. A hybrid T.

All of these furnish information on the magnitude of the standing wave ratio. In some cases, phase information may be obtained also, which information permits determination of impedance,[9] but this

knowledge, while useful in the laboratory, seldom is required in field work.

A block diagram of an arrangement employing a slotted line for measuring standing waves is shown in Figure 17. The oscillator source is commonly followed by a pad or attenuator to prevent frequency pulling. The slotted section may be either a coaxial or a wave guide line employing a mode which is not disturbed by the presence of the slot (for example, normal coaxial mode, $TE_{1,0}$ in rectangular wave guide, $TM_{0,1}$ in round wave guide). A traveling pick-up probe or loop projects through the slot and couples energy from the line into a detector which delivers direct current or audio frequency to the indicator. The probe is moved longitudinally to find points of maximum and minimum field strength. To avoid distortion of the field within the line, the probe should be small and should project only a short distance inside the slot. For accurate results, extreme care must be exercised in design and construction to avoid variation in depth of immersion as the probe is moved. Several slotted lines employed for standing wave measurements are shown in Figure 18.

A squeeze section consists of a section of rectangular guide with slots milled in the center of both broad faces so that the width of the guide can be varied by external deforming means. This changes the wave length in the guide, so that maximum and minimum values may be determined by a fixed probe and indicator.

The use of a directional coupler for standing wave measurement is discussed in the following section.

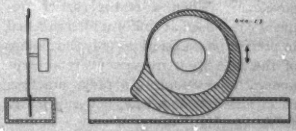
Another useful device for standing wave measurement is the hybrid $T$ or magic $T$. This is a sort of microwave bridge, consisting of a main wave guide to which an $E$ plane branch and an $H$ plane branch are joined in the same physical plane. With matched terminations of the two ends of the main guide, the two branches are conjugate. Terminating one end of the main guide in the unknown impedance and the other in a matched termination, the degree of impedance mismatch of the unknown is indicated by the magnitude of the reflected wave which appears in one branch when energy is fed into the other.

## Directional Couplers

Accurate measurement of transmitter power and receiver sensitivity requires a coupling path of known loss between the radar set and the test set. The first method employed for this was to place a portable test antenna (see Figure 2) in the field of the radar antenna. Depending on the frequency range, this test antenna took the form of a dipole,[10] with or without a small reflector, or an electromagnetic horn.[11] With this method, it was necessary to calibrate the loss of the space coupling path between the two antennas. Since it proved difficult to locate the test antenna at exactly the same point and to be sure that the main antenna pattern remained the same, a separate calibration of the coupling loss was usually required whenever a measurement was made.

An alternative method was to place a single probe in the radar transmission line. This introduced another sort of difficulty. Accuracy of measurement was vitiated by the presence of standing waves which rendered the probe pick-up a function of frequency and of location with respect to the irregularities. A highly satisfactory answer to the entire problem was found in a device which is called a directional coupler because it couples only to the wave propagated in one direction. In its simplest form, a directional coupler consists of two couplings to the main transmission line, which add for one direction of transmission and cancel for the other. Thus, for example, Figure 10A shows a form of directional coupler for wave guide which is placed in the radar transmission line at the point indicated schematically in Figure 1. An auxiliary wave guide is coupled to the main guide through two identical orifices spaced $\lambda g/4$ between centers (or more generally $n\lambda g/4$, where $n$ is an odd integer). Assuming the incident and reflected waves in the main guide to be directed as shown and the auxiliary guide to be terminated on one end, a test circuit connected to the other end will be coupled to the incident wave, while theoretically the two couplings to the reflected wave will differ by $\lambda/2$ and therefore cancel one another.

With such a device, measurements may be made of the characteristics of the incident wave independently of reflections.



(A) STRIP MOVING VERTICALLY IN GUIDE

(B) WAVE GUIDE BELOW CUTOFF

**Figure 23. Microwave attenuators**

If the coupling to the main line is not too close, there is no appreciable effect on the incident wave, and continuous monitoring can be had. Conversely, test signals applied through the directional coupler will travel in the main guide in the proper direction for testing the radar receiver.

If the locations of the termination and the test connection point in Figure 19A are reversed, the couplings to the main transmission line also are reversed. Such an arrangement therefore permits measurement of the reflected power, which in turn makes it possible to adjust for minimum reflected power and hence for minimum standing wave ratio. Comparison of the reflected power with the direct power determines the standing wave ratio. For convenience in measurement, two directional couplers pointed in opposite directions are frequently used, the combination being referred to as a bidirectional coupler (Figure 19B). One advantage of this arrangement is that the ability to measure the reflected power from the antenna and that part of trans-

**Figure 22. RF loads for different bands in the microwave frequency range**

mission line beyond the coupler provides means for detecting trouble in that part of the system. Directional couplers may be applied to any type of transmission line. Figure 19C shows a simple form of directional coupler for a coaxial line.

One characteristic of importance in a directional coupler is the coupling loss. A small value of coupling loss affords increased sensitivity of measurement, while a sizable value is desirable to minimize reaction on the main transmission line, as well as for other reasons. A loss of around 20 decibels has usually been found a good compromise. It is now the practice to incorporate a directional coupler in every radar set to obtain a test connection point.

Because of unavoidable imperfections, a directional coupler never gives complete cancellation for the undesired direction of transmission. The departure from ideality is indicated by the directivity (also referred to as front-to-back ratio), which is defined as the scalar ratio of the two powers measured at the test connection point when the same amount of power is applied to the main guide, first in one direction and then in the other. For measurements of the direct wave and of receiver characteristics, a moderate directivity, of the order of 15 decibels or better is sufficient. In measuring reflected power, however, the directivity determines the amount of direct power which appears at the point of measurement, and therefore controls accuracy. The chart of Figure 20 will facilitate determination of the maximum error that may occur in measuring different values of the standing wave ratio with various assumed directivities.

With a simple two-hole coupler, the directivity deteriorates rapidly as the frequency departs from that corresponding to quarter-wave spacing. By providing additional couplings suitably spaced, the residuals from different sets of couplings also can be cancelled against one another and the directivity versus frequency characteristic can be broadened materially. With multiple hole couplings, a minimum directivity of 26 to 30 decibels over a frequency band of 10 to 20 per cent is readily practicable in quantity production, and much better values are obtained in the laboratory. Some of the numerous designs of directional couplers developed for association with operating radar equipment are shown in Figure 21.

Because they are more convenient than slotted lines and can be made more accurate, directional couplers have been extensively used for standing wave ratio measurement in the laboratory. A number of special arrangements have been devised to improve both accuracy and convenience. A directional coupler arrangement which has been provided for field measurement of standing wave ratio in the vicinity of 25,000 megacycles also is illustrated in Figure 21. In this the direct power is brought to equality with the reflected power by an attenuator whose dial is calibrated directly in standing wave ratio. A wave-guide switch facilitates the power comparison.

## Auxiliaries and Components

An RF load (or dummy antenna) which will absorb the radar power in an impedance which matches the transmission line is very useful in radar work. Such a device permits testing the radar set in operating condition without actual radiation which might give information to the enemy or interfere with other radar equipment. It also makes it possible to test the radar set in locations where reflections from the ground or nearby objects otherwise would hamper or prevent a test. RF loads for microwave work usually consist of a section of transmission line (either coaxial or wave guide, depending on wave length) containing a high-loss dielectric. The impedance of such a load is necessarily low and must be matched to the radar line by tapering the dielectric over a distance of several wave lengths.[10] Moreover, if the line is to handle high power, tapering over a considerable length is necessary to distribute the heat.

A coaxial load preferably is tapered from outer conductor to inner conductor, since this both reduces the voltage gradient and facilitates heat dissipation. A dielectric consisting of a mixture of bakelite, silica, and graphite, molded in place, has been found satisfactory. For wave guides, a ceramic containing carbon may be preformed, with taper in one or two dimensions, and cemented in place.

Figure 22 shows a number of RF loads developed for different frequency bands. One of these, *TS-235/UP*, provides an excellent impedance match over the frequency range from 500 megacycles to above 3,000 megacycles. When equipped with a blower designed for uniform transverse ventilation, it will handle a peak power of the order of 750 kw with a duty cycle of about 0.001.

### Microwave Attenuators and Pads

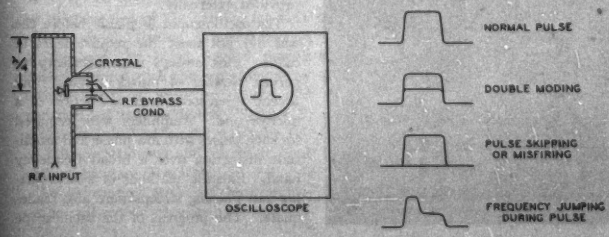
RF attenuators and pads are cornerstones of microwave testing. Attenuators are used to adjust unknown signals to levels suitable for measurement and to obtain the minute test signals required for measuring receiver characteristics. Pads serve to change levels and to prevent interaction between testing components. Microwave attenuators and pads are of two general types:

1. Those which employ dissipative elements to absorb power.
2. Nondissipative devices which introduce propagation or coupling loss.

For the shorter microwaves, the most convenient form of attenuator is of the dissipative type, employing a strip or vane of dielectric coated with a resistance material, as for example, carbon-coated bakelite. This is placed in rectangular wave guide with its plane paralleling the side of the guide. The attenuation is varied by varying the depth to which the vane is inserted in the guide (Figure 23A) or by changing its position in the guide. A valuable feature of such attenuators is that the minimum loss can be made substantially zero. For good impedance match, the strip must be tapered. By using two strips, the over-all length of the attenuator can be reduced. Extremely satisfactory attenuators of this type covering a frequency range of 8 to 12 per cent, with loss variable from 0 to 35 or 40 decibels, have been obtained in the frequency range 4,000 to 24,000 megacycles.

For the longer microwaves, where wave guides are inconveniently large, attenuators of the wave guide-below-cutoff type are very useful. These consist of a

Figure 24. Radar pulse envelopes



section of round wave guide the diameter of which is small compared with wave length and whose length is adjusted by telescoping. (See Figure 23B.) The $TM_{0,1}$ mode has been found very satisfactory, and $TE_{1,1}$ has also been used. Connection is made to the attenuator by a coaxial circuit at each end, with disk excitation for the $TM_{0,1}$ mode and loop coupling for $TE_{1,1}$. The attenuation formulas are[12]

$$TM_{0,1}. \quad A = \frac{41.8}{D}\sqrt{1-\left(\frac{1.31D}{\lambda}\right)^2} \quad \text{decibels per meter} \quad (12)$$

$$TE_{1,1}. \quad A = \frac{32.0}{D}\sqrt{1-\left(\frac{1.71D}{\lambda}\right)^2} \quad \text{decibels per meter} \quad (13)$$

where $D$ = diameter of wave guide in meters. Because of the effect of other modes when the coupling is close, a minimum loss of 20 to 30 decibels is required before the attenuation becomes linear with displacement. The attenuation differentials are substantially independent of frequency. Attenuators of this type present a large impedance mismatch at either end, the effect of which may be alleviated by padding or by a termination.

Types of pads employed in microwave work include the following:

1. Flexible coaxial cable, usually with high resistance inner conductor.
2. Coaxial $\pi$ with carbon-coated rod and disks.
3. Coaxial with carbon-coated rod as inner conductor.
4. Resistance strip in wave guide.
5. Directional coupler.

In calibrating microwave attenuators and pads, comparison with an accurately calibrated IF attenuator, using a heterodyne test set, has been found to give excellent results.

### RF Cables and Connectors

Flexible radio-frequency cables for connecting test equipment to equipment under test are an important adjunct of field testing. At frequencies of 10,000 megacycles and below, flexible coaxial cables of about 0.4-inch over-all diameter with solid or stranded inner conductor, solid low loss dielectric (polyethylene) and braided outer conductor have been used satisfactorily, although in the upper part of this range special measures have been necessary to prevent attenuation change caused by flexure and aging. Over most of this range, coaxial jack and plug connections have been found satisfactory, but wave guide connectors are preferable at the upper end. In the range above 10,000 megacycles, coaxial cables of requisite stability have not yet been obtained, and rubber-covered wave guide with soldered articulated joints is the best form of flexible cable now available.

### Oscilloscopes

Oscilloscopes are used extensively in radar maintenance for examination of video waves and for viewing RF envelopes. Satisfactory radar performance depends on a variety of video wave shapes, which may include trapezoidal or triangular pulses, sawtooth waves, square waves, or combinations of these. Observation of these wave shapes, supplemented if necessary by measurements of amplitude and duration, helps in diagnosing many troubles.

Examination of the envelope of the RF pulse is a convenient but less informative alternative to spectrum analysis. The envelope should be a clean, single trace of good shape. Figure 24 shows traces sometimes experienced. Double modding, that is, oscillating at different frequencies on different pulses, is shown by a double trace. Frequency-jumping during a pulse is shown by a break in the envelope. Misfiring gives a base line under the envelope. Other abnormalities in the RF envelope may result from incorrect video wave shape. Observation of the RF envelope requires a rectifier, usually a crystal, together with a suitable video amplifier. Since limitation of the oscilloscope to video functions permits general application to radar sets of all frequencies, the rectifier generally is provided externally.

The oscilloscopes available before the war did not meet the requirements of radar. Fast sweeps were necessary to permit viewing of pulses ranging from several microseconds to a fraction of a microsecond. Amplifiers were required for such pulses with low phase and amplitude distortion over a broad frequency band. Existing methods of synchronizing and phasing sweeps were also inadequate. The progress of the oscilloscope

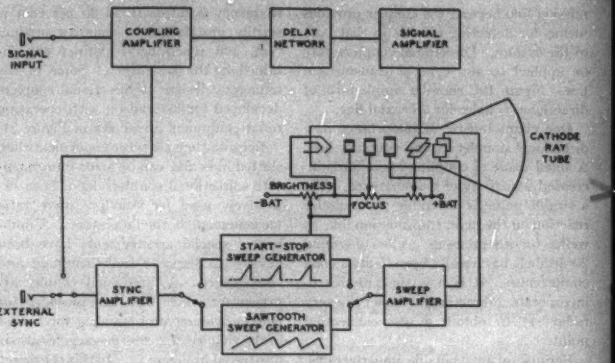



**Figure 26. Block diagram of *TS-34/AP* and *TS-34A/AP* oscilloscopes**

**Figure 25. Test oscilloscopes for viewing wave forms in radar equipments**

Left to right: *BC-910-A* (1942), *TS-34A/AP* (1944), and *TS-239/UP* (1945)

art during the war is illustrated in the successive designs of field test oscilloscopes shown in Figure 25.

The *BC*910*A* oscilloscope, gotten out as a stop gap not long after the attack on Pearl Harbor, incorporates fast sweeps and broad-band amplification. Following close upon this was the *BC*1087*A* (Navy code *CW*60*AAY*), which replaced sine-wave synchronization by a start-stop sweep triggered by the incoming pulses. This feature made it possible to superpose the erratic pulses produced by spark wheel and similar pulsers and at the same time avoided external synchronizing connections. A valuable feature conjoined with the start-stop sweep was a delay network in the main transmission path which gave the sweep time to start before the pulse reached the cathode-ray tube. This oscilloscope in original and modified form has seen wide service in all theaters. However, its weight of more than 60 pounds was a handicap for many uses.

Further advances in oscilloscope circuitry and in weight limitation resulted in *TS*-34/*AP*, weighing only 25 pounds. This combined the short-pulse features of the previous design with those of the conventional oscilloscope for viewing slower waves. A schematic diagram is shown in Figure 26. A redesign, coded as *TS*-34*A*/*AP*, incorporated variable start-stop sweeps and improved mechanical design. These two oscilloscopes, *TS*-34 and *TS*-34*A*, were produced to a total of some 12,000 and were used universally by all branches of the service for both radar and radio testing. Toward the end of the war the trend toward shorter pulses, coupled with the need for precise measurement of wave amplitude and duration, led to a new design, *TS*-239/*UP*, which embodied wide advances over *TS*-34*A* in performance and versatility but with an increase in weight.

In association with different oscilloscopes, other video devices have been employed. The amplitude of pulse applied to the magnetron is thousands of volts. To derive a voltage suitable for application to the oscilloscope, a voltage divider of the capacitor type is used (*TS*-89/*AP*). Suitable video terminations, dividers, and loads, sometimes of high voltage and power capacity, are required to obtain proper test conditions and provide convenient test points (*TS*-98/*AP*, *TS*-390/-*TPM*-4, *TS*-90/*AP*, *TS*-234/*UP*). Originally a high impedance connection to the oscilloscope was effected by a single-stage amplifier unit (*BC*1167*A*), but a simple divider-type of probe was later found more satisfactory for this purpose.

## Range Calibration

Types of timing circuits used for radar range determination include multivibrators, coil and capacitor oscillators (generally without but sometimes with temperature control), and occasionally quartz crystal oscillators. The first two depend for their accuracy on capacitors, resistances, coils and other elements which are subject to error due to aging, temperature, humidity, mechanical damage, and the like. Nor is the quartz crystal oscillator wholly immune to error. Consequently, portable range calibrators are required for field maintenance.

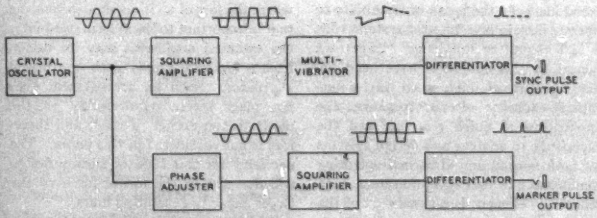



**Figure 27. Block diagram of *TS*-102/*AP* and *TS*-102*A*/*AP* range calibrators**

*TS*-102*A*/*AP* (Figure 27) and its predecessors, *TS*-102 and *TS*-19, are precision calibrators which have been extensively used for checking a large number of different air-borne bombing and gun-laying radar equipments, and ship-borne fire control and search radar equipments. These sets deliver accurately spaced marker pulses, derived from a quartz crystal oscillator, for checking the radar range pulses. A trigger pulse derived from a multivibrator synchronized with the quartz oscillator is also provided for actuating the radar timing circuits. With certain radars the calibration procedure requires an oscilloscope as well. Extreme stability of marker pulses, better than $\pm 0.02$ microsecond, is obtained. A stop watch is included in these sets for checking rate of change in range.

Less precision is required in range calibration of search radar sets. For this purpose the *TS*-5/*AP* calibrator provides marker pulses of one-quarter, one, five, or ten nautical or statute miles, derived from a coil and capacitor oscillator with closely controlled temperature coefficients. This calibrator is designed to be triggered by the radar or some other external source.

## Computer Test Sets

A number of radar sets are equipped with computers which receive the data on location of target and its direction and rate of change, together with essential related information on such factors as wind velocity, ground speed, altitude, and so forth, and deliver the solution of the ballistic problem in the form of a voltage which releases bombs, points the guns, or serves other purposes. Means for checking the accuracy of these computing devices are generally required. The type of test set needed depends upon the computer design, which has taken different forms according to the nature of the problem and the state of the art.

Two types of computer test sets are

**Figure 28. Two test sets for checking the computers used in bombsight and fire control radar sets**

shown in Figure 28. *TS-158/AP*, designed for use with certain air-borne bombing radars, furnishes to the computer a signal representing a target approaching at known speed and checks the accuracy of bomb release. *TS-434/UP*, designed for several air-borne and ground radars is an accurate instrument for determining the voltage ratios at various points in a computer and thus checking its performance.

## Conclusion

More than 200 different designs of test sets were developed during the war by Bell Laboratories to meet the exacting requirements of radar field maintenance. These differed radically from previous art. Outstanding features were portability, precision, and generality of application. The large number of designs are caused partly by the varied functions of radar and the varied conditions of use. Largely, however, it results from the fact that the frequency band that can be handled in any one set is limited, whereas many frequency ranges and subranges had to be covered in all.

Altogether, more than 75,000 radar test sets were manufactured by Western Electric Company, and these were used in all theaters of war by the United Nations forces. The production rate at the end of the war exceeded 5,000 test sets a month. In numerous cases, moreover, small preproduction quantities of test equipment were built on a "crash" basis for special missions and for training purposes. The test equipment produced for the field had to be more precise than the radar sets, and the equipment used in the factory and the laboratory to test the field test equipment had to be still more precise.

Trends of development at war's end were toward

1. Further broadbanding, simplification, and precising.
2. Coverage of new frequency ranges.

## References


1. Ultra-High Frequency Techniques (book). J. G. Brainard, G. Koehler, H. J. Reich, L. F. Woodruff. D. Van Nostrand Company, Inc., New York, N. Y., 1942.
2. Reflex Oscillators. J. R. Pierce. *Proceedings of the Institute of Radio Engineers*, volume 33, February 1945, page 112.
3. The Lighthouse Tube. E. D. McArthur, E. P. Peterson. *Proceedings of National Electronics Conference*, volume I, 1944, page 33.
4. Electromagnetic Waves (book). S. A. Schelkunoff. D. Van Nostrand Company, Inc., New York, N. Y., 1943.
5. The Proportioning of Shielded Circuits. E. I. Green, F. A. Leibe, H. E. Curtis. *Bell System Technical Journal*, volume 15, April 1936, page 348.
6. Resonant Lines in Radio Circuits. F. E. Terman. AIEE Transactions, volume 53, July 1934, pages 1046–53.
7. Ultra-Short-Wave Transmission Phenomena. C. R. England, H. T. Crawford, W. W. Mumford. *Bell System Technical Journal*, volume 14, July 1935, page 389.
8. Thermistors in Electronic Circuits. R. R. Batcher. *Electronic Industries*, volume 4, January 1945, page 76.
9. An Impedance Transmission Line Calculator. P. H. Smith. *Electronics*, January 1944.
10. Microwave Transmission (book). J. C. Slater. McGraw-Hill Book Company, New York, N. Y., 1942.
11. Theory of the Electromagnetic Horn. W. L. Barrow, L. J. Chu. *Proceedings of the Institute of Radio Engineers*, volume 27, January 1939, page 51.
12. Attenuation of Electromagnetic Fields in Pipes Smaller Than Critical Size. E. G. Lindner. *Proceedings of the Institute of Radio Engineers*, volume 30, December 1942, page 554.


# Motor-Driven Exciters for Turbine Alternators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THIS PAPER presents a study of the performance of a motor-driven excitation set designed for large turbine alternators connected to modern power systems. This excitation set has been so designed that its performance, both steady state and transient, is essentially comparable with the usual direct-connected (shaft-driven) exciter even when the driving motor is receiving its voltage from the alternator to which the generator is supplying excitation.

A significant trend to the unit type of generating station,[1,2] with each generator connected by its high-voltage transformer to the transmission system, has been evolving during the last 20 years. This trend has been the result of the ability to operate large inter-connected systems with a high degree of reliability. Important factors in this evolution have been the development of high-speed high-interrupting-capacity circuit breakers, the application of quick relaying, and the experience to analyze and design systems for both normal and abnormal operating conditions. In this type of system, each generating element is a small part of the total capacity, and complete reliance on its operation is not so essential as is the reliable performance of the major transmission system. Transmission line links are required to carry blocks of power of greater magnitude than the output of individual generating units. The system is accordingly able to withstand the loss of any single unit of generation more easily than the loss of important line capacity. An element of generation may be quickly disconnected as a unit because of out-of-step operation or any other trouble. In this way the disturbance is localized and more easily cleared. Serious system disturbances, resulting in load interruptions, usually involve more than one generating element or station and are the result of failure to localize the initial trouble.

For the type of station and system where the loss of an individual generating unit is important to the system reliability, the essential auxiliaries may be driven from a separate supply such as a house alternator. Such an arrangement does not place severe requirements on the motor-driven exciter, if used, and therefore is not considered in this paper. The necessity for this type of station design will decrease in the future for even the larger capacity generating units.

With this trend in station and system design, it is natural that the essential auxiliaries of a generating element should more and more obtain their power from an auxiliary bus connected by a transformer to the alternator terminals. This practice has found considerable favor, with the possible exception of the exciter of the main generating unit. The exciter is one of the most important essential auxiliaries, and since its output is usually increased several times at the time of a system disturbance or low system voltage, it is understandable that direct-connected exciters should continue to be used in-


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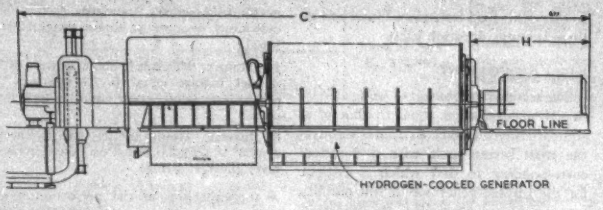


**Figure 1. Outline of typical 30,000-kw 3,600-rpm turbine alternator showing comparative over-all dimensions for three types of excitation systems**

| Excitation system: | C | H |
|---|---|---|
| Direct drive, | | |
| 3,600 rpm | 50 ft 4¼ in | 9 ft 4 in |
| Gear drive, | | |
| 1,776 rpm | 52 ft 11⅞ in | 11 ft 11⅝ in |
| Motor drive | 44 ft 2¼ in | 3 ft 2 in* |

Dimensions of motor-driven exciter set:
Length—10 ft 11 in
Width—3 ft 10¼ in
Height—4 ft ¾ in
* Length to end of alternator shaft.

stead of the more flexible separately driven exciters. However, with these modern systems it is now possible, as will be shown in this paper, to design a motor-driven exciter set which will have a reliability comparable with that of the other essential auxiliary drives.

Motor-driven exciters for turbine-alternators have the following, rather self-evident, advantages over the conventional high-speed exciters which are direct-driven from the shaft of the main alternator:

1. A motor-driven excitation set can be of unit construction, and it can be installed in locations less expensive than those required by a direct-driven exciter.

2. The motor-driven exciter can be designed without gearing for a lower and more satisfactory speed for a d-c generator of its rating.

3. The design and construction of the main alternator unit is simplified.[3,4]

In Figure 1 is shown an outline drawing of a typical 30,000-kw turbine-alternator set, and on this are given the over-all lengths when each of the three major types of excitation systems is used: direct-drive, gear-drive, and motor-drive. Note that the over-all length of the turbine-alternator set using the motor-driven exciter is almost nine feet less than the over-all length of the turbine-alternator set using the gear-driven exciter. The principal dimensions of a special motor-driven 1,200-rpm exciter of co-ordinated design for a typical 30,000-kw turbine-alternator are shown in Figure 2.

Reasons for the former poor reputation of motor-driven exciters, and the modern developments which have tended to minimize the importance of these reasons, may be summarized as follows:

1. Before the use of modern switches and relays, the motor-driven exciter connected to the main system was not capable of maintaining the alternator excitation at the high values demanded during loss of synchronism and resulting periods of prolonged low voltage. This requirement, however, largely has been eliminated by better system design and modern apparatus.

2. During a period of low system frequency and consequently low motor speed, motor-driven exciters, when operated under manual control of excitation, are likely to reduce the excitation to a point where generator instability can result. This tendency was increased at such periods by the speed governor's trying to increase the kilowatt load of the alternator. With the use of modern voltage regulators, however, the desirability or necessity for operating under manual control has been eliminated. Also, the frequency change during a system emergency is now generally less as a result of the increased inter-connected system capacity.

Because of the developments outlined in the foregoing, it becomes desirable to re-evaluate the field of application for the motor-driven exciter. To fulfill the requirements of a reliable excitation source, a motor-driven exciter must be designed to meet the following performance specifications. These specifications should be met even with the driving motor receiving its voltage from the alternator to which the generator is supplying excitation so as to conform with the trend toward the simplified unit type of generator station design:

1. Maintain and develop excitation equal to that of a direct-connected exciter for alternator terminal voltages down to 70 per cent of normal for sustained periods.

2. Provide excitation equal to that of a direct-connected exciter through the most severe fault that the alternator itself can withstand without losing synchronism when operating at full rated steam flow.

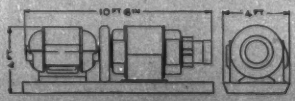


**Figure 2. Outline of motor-driven excitation set of co-ordinated design for 30,000-kw turbine alternator**

The above requirements, as will be demonstrated, can be obtained by the following three design features:

1. Co-ordinated design of turbine alternator, exciter, and voltage regulator.

2. Induction motor designed with sufficient torque margin to meet the condition of ceiling excitation voltage with 70 per cent alternator terminal voltage (requirement 1 preceding).

3. Sufficient additional flywheel effect for the exciter set so that reasonably rapid excitation can be applied for fault duration and severity which are not quite sufficient to cause loss of synchronism of the turbine alternator at full output (requirement 2 preceding).

## Determination of Characteristics

The following is a discussion of the basis for the selection and design of a motor-driven exciter to meet the two previously defined performance requirements, that is, prolonged low system voltage and severe system faults. A motor-driven exciter set for a 30,000-kw turbine alternator built to these general system requirements was furnished the Dayton Power and Light Company. See Figures 3 and 4.

### Low System Voltage Requirement

System disturbances may occur in which the system voltage may become comparatively low for relatively prolonged periods of time. A lower system design limit for this condition may be taken as 70 per cent voltage existing for a period of about three minutes.

For a system voltage of this magnitude and duration, difficulty will begin to be experienced with the other essential auxiliaries of the station; the system loads may begin to show a cumulative increase in reactive current requirement because of stalling of induction motors; and the heavily loaded system ties will tend to open because of loss of synchronism. This value of voltage and duration, therefore, seems reasonable as a design value for a motor-driven exciter. Up to these limits the turbine alternator should be capable of making a full contribution to the restoration of normal system conditions in order to prevent and reduce the possibility of such a cumulative breakdown of system interconnection and interruption of system loads. Dif-

ferent limits may, in some cases, be deemed necessary to meet a particular system condition. Operating experience and oscillographic records may indicate that more or less severe limits may be needed as the design values for the set. The important point is that the characteristics of the motor-driven exciter need not be haphazardly selected but can be designed to meet the requirements of the system.

In determining the pullout or maximum torque for which the motor should be designed, the low-voltage condition is the determining factor rather than any of the requirements for transient stability of the alternator. With the motor size determined by the low-voltage condition, a study of the duration and magnitude of this voltage, together with the probable alternator and exciter temperatures at which this condition occurs, must be made in order to obtain an excitation system with the best compromise among size, cost, losses, and pullout power. For instance, an induction motor which must furnish ceiling excitation with 60 per cent voltage at its terminals and with the alternator in the cold (25 degrees centigrade) condition will be about three times as large as one for which it is felt adequate to design for 80 per cent voltage in the hot (125 degrees centigrade) condition, and is about 1.7 times as large as a motor designed for 70 per cent voltage with the alternator and exciter temperatures midway between the hot and cold conditions.

The motor-driven excitation set for the Dayton Power and Light Company was designed for 60 per cent voltage at the motor terminals with the alternator and exciter at 75 degrees centigrade; the thermal capacity of the motor is sufficient to carry this load for isolated intervals of three minutes duration each.

**Figure 3. 30,000-kw 3,600-rpm turbine alternator of Dayton Power and Light Company, designed for use with motor-driven exciter of Figure 4**

### Fault Requirement

The second requirement of being able to supply an excitation equal to that of a standard direct-connected exciter through the most severe fault with a duration corresponding to that which is critical for the turbine generator at full output, requires a consideration of the transient performance of the main unit and of the motor-driven exciter.

In Figure 5 is given the hypothetical system on which transient stability calculations were made to determine the operating performance of an alternator with a motor-driven excitation set. The alternator is connected to an infinite system through a step-up transformer of 10 per cent reactance and a tie-line of 25 per cent reactance. A 3-phase fault through zero impedance is assumed to occur on a stub feeder located immediately on the high side of the alternator transformer. Based on constant flux linkages, the critical switching time for this system is 0.27 second; for the calculations of Appendix I, which include the effect of flux decay, a switching time of 0.25 second is assumed. The induction motor driving the excitation set is supplied through a transformer whose high side is connected directly to the generator terminals.

This time of 0.25 second or 15 cycles for a severe 3-phase fault will be recognized as typical for the critical time of a 3-phase fault for turbine generators. Most modern systems have fault clearing times at least as low as this at and near their important generating stations, particularly when it is important for the maintenance of stability of the generating capacity.

Based on these considerations, the motor-driven exciter designed for the Dayton Power and Light Company was built having the following characteristics:

1. Exciter: 4.0* per unit ceiling exciter voltage at motor synchronous speed; 2.0 per unit (American Standards Association definition) response at motor synchronous speed.

2. Motor: Maximum shaft power with normal voltage equal to 34 per unit.** Slip at maximum power equal to nine per cent.

3. Inertia: Motor, exciter, and flywheel; $H=32$*** ($H \geq 5.0$ based on exciter nameplate kilowatt rating).

A comparison of the performance of this exciter with one of less inertia and pullout power and also with a direct-driven exciter is summarized by Figure 6,

**Figure 4. Motor-driven exciter for 30,000-kw turbine alternator of Dayton Power and Light Company of Figure 3**

which shows the variation in alternator terminal voltage following the application and clearing of a 3-phase fault. A more complete explanation of the basis for these results, with a more detailed comparison, is given in Appendix I. It will be noted that for the case of a 3-phase high-voltage fault lasting for 0.25 second, a motor-driven exciter of proper design can be as effective as a direct-driven exciter in returning the voltage to normal and preventing loss of alternator synchronism. On the other hand, a motor-driven exciter without adequate motor power or inertia may result in loss of synchronism and, in general, in poorer performance than the conventional direct-driven exciter. This shows the importance of co-ordinating the motor and exciter design with the alternator and system characteristics.

## General Design Principles

In order to insure that adequate inertia, pullout, and over-all reliability are built

* Unit exciter voltage is the exciter voltage necessary to provide normal no-load alternator voltage on the air gap line with the alternator field at 75 degrees centigrade.

** Unit field power is the power supplied to the alternator field (75 degrees centigrade) with the alternator at no-load, normal voltage on the air gap line; unit field power is approximately one-sixth of the exciter nameplate rating.

*** The inertia constant, $H$, is based upon unit power as defined directly above and the total inertia of the entire excitation set.

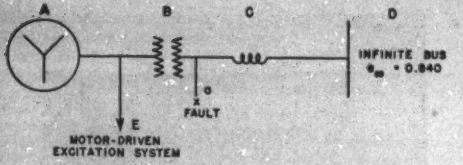


**Figure 5A (above). Assumed typical system**

*A*—Alternator
*B*—Line transformer
*C*—Line reactance
*D*—Infinite bus
*E*—Supply to motor-driven excitation system
*a*—Stub feed on which fault occurs

Alternator: $x_d = 1.25$; $x_q = 1.19$; $x'_d = 0.13$; $T'_{do} = 5.25$ seconds; $H = 5.40$ (turbine and generator)
Line transformer: $x = 0.10$
Line: $x = 0.25$
Fault: 3-phase fault on stub-feeder at *a*; fault cleared in 0.25 seconds

into the motor-driven excitation set, the following design principles must be taken into consideration:

1. During severe faults, the induced alternator field currents cause the maximum exciter power to reach values of the order of 3.5 times the exciter nameplate rating. Subsequent to the clearing of the fault, the alternator swings coupled with the action of the voltage regulator will cause exciter loads of the order of three times the exciter nameplate rating.

2. The loads discussed in the preceding paragraph must not in any way cause collapse of the exciter voltage, since the primary duty of an exciter during system disturbances is to furnish sufficient excitation voltage to arrest and reverse, as quickly as possible, the flux decay in the alternator caused by the high induced field currents.

3. The exciter must be capable of handling, without failure, the large field currents which are induced during alternator terminal faults. These currents may reach values of the order of 5 times the exciter nameplate rating.

4. During any prolonged low-voltage period, the exciter will go to its ceiling excitation and remain there for the duration of the low voltage. During this period the alternator field current will be determined approximately by the alternator field resistance and the exciter voltage, as the induced field currents will not have a major effect.

5. During low-voltage periods of the type described in the preceding paragraph, the maximum exciter load will occur with the alternator and exciter in the cold (25 degrees centigrade) condition. If the exciter ceiling voltage with a cold exciter is ten per cent greater than the ceiling with a hot exciter, the exciter load with both alternator and exciter in the cold condition is 170 per cent of the exciter load when the alternator (125 degrees centigrade) and exciter are in the hot condition.

6. Transformers and other apparatus between the motor terminals and the alternator lines will cause the motor voltage to be lower than the alternator voltage during system disturbances.

7. During high-voltage transmission system faults for a unit type of generating station, a practical lower limit of the motor voltage will be about 30 per cent. Sufficient inertia must be built into the excitation set to carry it through this fault period without its speed decreasing to values so low as to cause collapse of the exciter voltage.

8. The main exciter and pilot exciter themselves must be designed so that the main exciter voltage will not collapse when the speed drops to the maximum slip for which the excitation set was designed.

9. The motor pullout must be high enough to prevent exciter voltage collapse during any prolonged low-voltage condition. In particular, the motor must be capable of maintaining excitation during low-voltage periods even with the alternator and exciter in the cold condition.

10. The exciter ceiling voltage must be high enough so that even with the maximum motor slip the ceiling voltage is equal to that of a conventional direct-driven exciter. An upper design limit, however, must be placed on the maximum ceiling voltage which occurs with the exciter in the cold condition, since too high a ceiling voltage at this point may produce pullout of the induction motor.

11. In order to provide the maximum reliability of operation, it is necessary to have the alternator under automatic voltage regulator control; otherwise a system disturbance results in reduction of alternator field excitation. Greater reliance can be placed on the voltage regulator when it is provided with a lower limit of excitation which is varied with valve position or steam flow. This was accomplished in the Dayton Power and Light Company's installation by using a new type of direct-acting voltage regulator with a simple type of variable lower limit. See Figure 7 for a schematic diagram of the excitation system and Figure 8 for a photograph of the regulator.

## Voltage Regulator

The automatic voltage regulator used in the Dayton Power and Light Company's installation is a sturdy mechanical device consisting essentially of a torque motor and a simple spring-mounted contact system connected to taps on the regulating resistor. The design of the device is as simple mechanically as is consistent with the desired accuracy of regulation. The arrangement of parts is apparent from Figure 8.

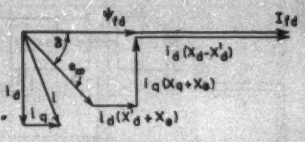


**Figure 5B (right). Vector diagram of assumed system. Line and transformer are grouped together in the above diagram as $x_e$; saturation and resistance are neglected**

The torque-motor, excited from the alternator terminal voltage through suitable transformers, resistors, and rectifiers, operates silver contacts by means of the lever, varying resistance in the exciter field circuit to maintain alternator terminal voltage at the desired value. An equalizing reactor in combination with a current transformer is provided to assure proper division of reactive kilovolt-amperes where two or more similar equipments are used on machines in parallel. A lower limit on excitation which varies with steam flow is obtained by a rheostat attached to the control valve cam shaft. The rheostat, connected in parallel with the regulating resistance of the voltage regulator as shown in Figure 7, determines as a function of steam flow the maximum resistance which can be inserted in the main exciter field circuit. This lower limit is effective for either manual or automatic control of excitation.

This direct-acting voltage regulator provides, in a simple mechanical device:

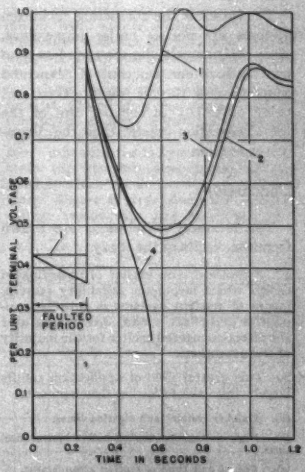


**Figure 6. Alternator terminal voltage (see Appendix II)**

1—Constant alternator field flux linkages
2—Conventional direct-driven exciter
3—Adequate motor-driven exciter
4—Inadequate motor-driven exciter

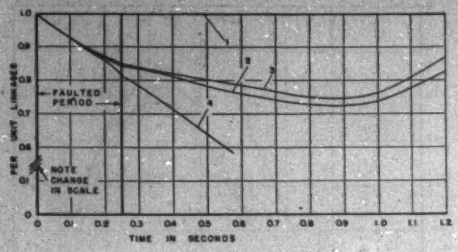


**Figure 11. Alternator field flux linkages**

1—Constant alternator field flux linkages
2—Conventional direct-driven exciter
3—Adequate motor-driven exciter
4—Inadequate motor-driven exciter

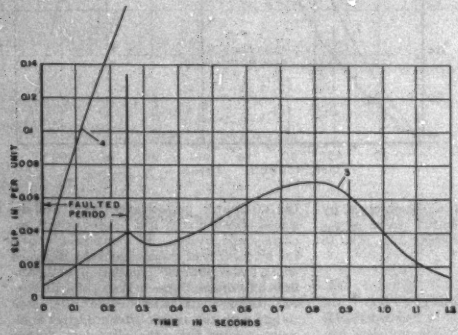


**Figure 12. Slip curves**

1—Constant alternator field flux linkages
2—Conventional direct-driven exciter
3—Adequate motor-driven exciter
4—Inadequate motor-driven exciter

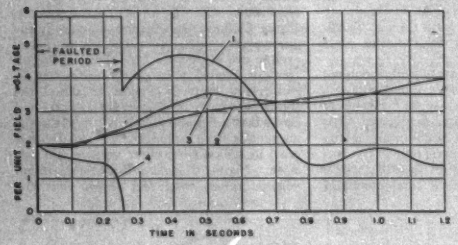


**Figure 13. Alternator field voltage**

1—Constant alternator field flux linkages
2—Conventional direct-driven exciter
3—Adequate motor-driven exciter
4—Inadequate motor-driven exciter

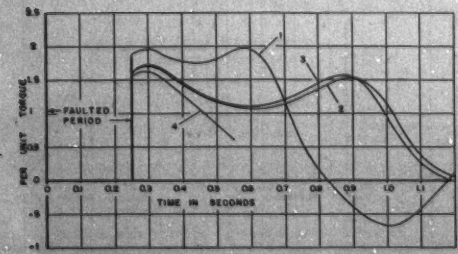


**Figure 14. Alternator torque**

1—Constant alternator field flux linkages
2—Conventional direct-driven exciter
3—Adequate motor-driven exciter
4—Inadequate motor-driven exciter

motor-driven exciter maintains higher alternator voltage than the direct-driven exciter for the conditions of this comparison. On Figure 13 are shown the exciter voltage curves, and the motor-driven exciter voltage is higher than the direct-driven exciter voltage for almost the entire period. On Figure 14 are shown the alternator torque curves; the motor-driven exciter maintains a higher alternator torque than the direct-driven exciter except around one second when the torque of case 3 becomes lower than that of case 2 because the alternator is swinging back past the initial angle, and the swing with the motor-driven exciter is less than the swing with the direct-driven exciter, thereby indicating a greater stability margin with the motor-driven exciter.

Case 4 is of particular practical interest as it shows the alternator instability which may develop if the motor-driven excitation set is not designed with sufficient inertia and pullout. Figure 10 shows how the alternator displacement angle increases without limit. Figure 12 shows how the driving motor begins to stall, and Figure 6 shows how the alternator voltage decreases toward zero.

These results show that with the quick switching times of modern systems, it is possible to build motor-driven exciters whose performance is comparable with that of the direct-driven exciter.

## Appendix II. Comparative Characteristics of Excitation Systems

The comparative transient performance of a turbine-generator excited by various excitation systems is given by the following figures. (Details pertaining to the calculation of the curves of these figures are given in Appendix I.)

Figure 6—Terminal voltage versus time.
Figure 9—Torque-angle curves.
Figure 10—Displacement angle versus time.
Figure 11—Field flux linkages versus time.
Figure 12—Motor slip versus time.
Figure 13—Field voltages versus time.
Figure 14—Torque versus time.

The numbers on the curves of the above figures refer to the various excitation systems and are defined as follows:

1. Constant alternator field flux linkages.

2. Conventional direct-driven exciter (direct-driven from shaft of turbine-generator); 3.0 ceiling; 1.0 response.

3. Motor-driven exciter with adequate inertia and motor power. Exciter: 4.0 ceiling at motor synchronous speed; 2.0 response at motor synchronous speed. Motor: maximum shaft power (1.0e) = 34 per unit;* slip at maximum power = 9 per cent; inertia: motor, exciter, and flywheel; $H = 32$.**

4. Motor-driven exciter with inadequate inertia and motor power. Exciter: 3.0 ceiling at motor synchronous speed; 1.0 response at motor synchronous speed. Motor: maximum shaft power (1.0e) = 12 per unit;* slip at maximum power = 10 per cent. Inertia: motor and exciter (no flywheel); $H = 0$.**

* Unit field power is the power supplied to the alternator field with the alternator at no-load, normal voltage on the air-gap line; unit field power is approximately one-sixth of the exciter nameplate rating.

** The inertia constant $H$ is based upon unit power as defined directly above, and the total inertia of the entire excitation set.

## Appendix III. Alternator Calculation

| | | | |
|---|---|---|---|
| 1. | Time in seconds at center of interval | $t$ | $n$ |
| 2. | Displacement angle from swing sheet | $\delta$ | $n$ |
| 3. | $d$-axis field-winding flux | $\psi_{fd}$ | $n$ |
| 4. | $e_\infty \cos \delta$ | $e_\infty \cos \delta$ | $n$ |
| 5. | $(x'_d+x_a)i_d=\psi_{fd}-e_\infty \cos \delta$ (3–4) | $(x'_d+x_a)i_d$ | $n$ |
| 6. | $i_d$ | $i_d$ | $n$ |
| 7. | $(x_q+x_a)i_q=e_\infty \sin \delta$ | $e_\infty \sin \delta$ | $n$ |
| 8. | $i_q$ | $i_q$ | $n$ |
| 9. | $i_q e_\infty \sin \delta$ (6×7) | $i_q e_\infty \sin \delta$ | $n$ |
| 10. | $i_q e_\infty \cos \delta$ (8×4) | $i_q e_\infty \cos \delta$ | $n$ |
| 11. | $i_q e_\infty \sin \delta+i_q e_\infty \cos \delta=T$ | $T$ | $n$ |
| 12. | $(x_d+x_a)i_d$ | $(x_d+x_a)i_d$ | $n$ |
| 13. | $e_\infty \cos \delta$ | $e_\infty \cos \delta$ | $n$ |
| 14. | $I_{fd}=(x_d+x_a)i_d+e_\infty \cos \delta$(12+13) | $I_{fd}$ | $n$ |
| 15. | $E_{fd}$ from g of Appendix IV | $E_{fd}$ | $n$ |
| 16. | $T'_{do}p\psi_{fd}=E_{fd}-I_{fd}$(15–14) | $E_{fd}-I_{fd}$ | $n$ |
| 17. | $\frac{E_{fd}-I_{fd}}{T'_{do}}=\frac{\Delta\psi_{fd}}{\Delta t}$ | $\frac{\Delta\psi_{fd}}{\Delta t}$ | $n$ |
| 18. | $\frac{\Delta\psi_{fd}}{\Delta t}\times\Delta t$ with $\Delta t=0.05$ second. ($\Delta t=0.025$ second for discontinuous points) | $\Delta\psi_{fd}$ | $n$ |
| 19. | $\psi_{fd}$ of preceding interval and $\Delta\psi_{fd}$ | $\psi_{fd}$ | $n+1/2$ |
| 20. | Time at end of interval | $t$ | $n+1/2$ |
| 21a. | $I_{fd}$ (14) | $I_{fd}$ | $n$ |
| 21b. | $x_d i_d$ | $x_d i_d$ | $n$ |
| 21c. | $e_{td}=I_{fd}-x_d i_d$ (21a–21b) | $e_{td}$ | $n$ |
| 22. | $e_{tq}=x_q i_q$ | $e_{tq}$ | $n$ |
| 23. | $e_t=\sqrt{e^2_{td}+e^2_{tq}}$ | $e_t$ | $n$ |

## Appendix IV. Induction Motor Calculation

| | | | |
|---|---|---|---|
| (a). | Time in seconds at center of interval | $t$ | $n$ |
| (b). | $e_t$ from 23 of Appendix III | $e_t$ | $n$ |
| (c). | Slip at time $t$ | $s$ | $n$ |
| (d). | $kw_m$ = input to induction motor = $Pe_t^2$. ($P$ at slip $s$ is obtained from power slip curve) | $kw_m$ | $n$ |
| (e). | Exciter response for zero slip | $\Delta E_{fd}(s=0)$ | $n$ |
| (f). | Exciter voltage for zero slip $E_{fd}(s=0)$ of preceding interval plus $\Delta E_{fd}(s=0)$ | $E_{fd}(s=0)$ | $n$ |
| (g). | Actual exciter voltage = $(1-s)^2 E_{fd}(s=0)$ | $E_{fd}$ | $n$ |
| (h). | $I_{fd}$ from 14 of Appendix III | $I_{fd}$ | $n$ |
| (i). | Kilowatts delivered to alternator field = $E_{fd}\times I_{fd}$ | $kw_g$ | $n$ |
| (j). | $kw_m-kw_g(d-i)$ | $\Delta kw$ | $n$ |
| (k). | $\Delta kw$ of $j\times\Delta t$ with $\Delta t=0.05$ second ($\Delta t=0.025$ second for discontinuous points) | $\Delta kw$ seconds | $n$ |
| (l). | $kw$ seconds of preceding interval plus $\Delta kw$ seconds | $kw$ seconds | $n+1/2$ |
| (m). | $\sqrt{\frac{kw \text{ sec of } 1}{H \text{ of excitation system}}}$ = speed | $\delta$ | $n+1/2$ |
| (n). | Slip at end of interval = $1-s$ | $s$ | $n+1/2$ |
| (o). | Time at end of interval | $t$ | $n+1/2$ |

# Arcing Ground Tests on a Normally Ungrounded 13-Kv 3-Phase Bus

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THE BUSSES and connected equipment in electric power stations sometimes are operated ungrounded. When a single insulation fault to ground occurs on a system of this type, the fault current is relatively small, the arc damage usually slight, and the faulted equipment in nearly all cases can be removed from service without relay action or service disturbance of any kind. However, in April 1942, faults developed simultaneously at two points 300 feet apart on the ungrounded 60-cycle 13.2-kv bus in the Holtwood station of the Pennsylvania Water and Power Company. This trouble resulted in severe arcing and damage to the bus structure before the faults were isolated.

It is unlikely that two insulators at a distance from each other would fail simultaneously without some electrical disturbance initiated by the failure of one causing the failure of the other. Numerous studies of ungrounded electric systems have been published which show that overvoltages as high as six to eight times normal theoretically can occur when a ground fault produces an arc.[1,2,3,7] This paper describes an experimental determination of the magnitude of overvoltages produced by several types of arcing grounds on the Holtwood bus, and complementary tests and analyses to determine the nature of the phenomena responsible for the insulation failures and the forced outage. The investigation differed from those previously described in technical literature in that experimental work was done with actual high voltage arcs to ground on a 13-kv station bus rather than on a high-voltage transmission line or a low-voltage theoretically equivalent circuit.

Because the work reported here was done only with arcing grounds on a 13-kv normally ungrounded station bus, conclusions are limited to only this class of service and do not include high-voltage transmission line phenomena or effects of switching surges.

## Scope of Investigation

The investigation involved the following steps:

1. As an introduction to arcing ground phenomena on a 3-phase bus, a study was made of the electrical vector relationships involved.

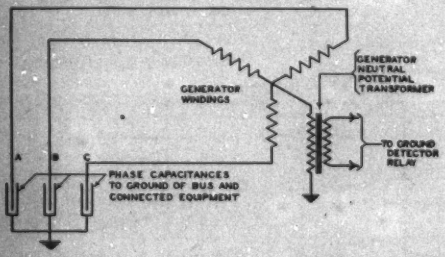


Figure 1. Simplified equivalent circuit of Holtwood 60-cycle bus

2. A study of the high-frequency characteristics of the bus and connected equipment was made to determine whether standing waves could have contributed to the generation of very high voltages on the Holtwood bus.

3. The characteristics of arcs under simulated arcing ground conditions were studied on a laboratory scale. Arc gaps were developed which had, as nearly as practicable, the characteristics theoretically required for the production of high voltages by arcing grounds.

4. Arcing grounds at high voltages were placed on the Holtwood bus under progressively more severe conditions, to determine if high overvoltages could be produced by any arcing ground condition likely to occur in service.

5. An analysis was made to determine whether the neutral voltage fault detecting method installed on the Holtwood bus can warn of impaired insulation to ground before the insulation is completely broken down. The analysis is included as an appendix to this paper. Curves were developed which can be used to determine easily the sensitivity of this type of detector to reduced insulation resistance in any similar installation.

## The Vector Relationships on an Ungrounded 3-Phase Bus

An ungrounded bus system has distributed capacitances between each phase conductor and ground whose charges supply the current through a ground fault. When examining the vector relationships of the voltages and currents involved, the phase-to-ground capacitances can be considered as three equal lumped constants connected as shown in Figure 1.

In normal operation, the capacitances have the phase-to-neutral voltages $E_{OA}$, $E_O$', and $E_{OC}$, shown in Figure 2A, impressed upon them. The simplest type

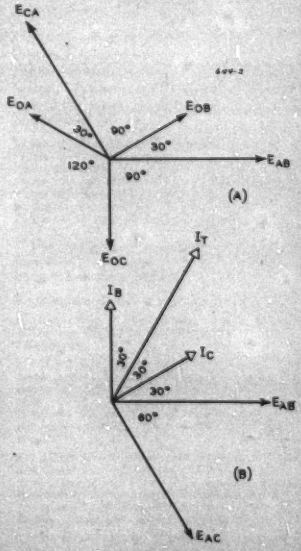


Figure 2. Vector relationships on a 3-phase bus

A—Voltage vectors

B—Voltage and charging current vectors with A-phase grounded

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of ground fault to examine is a solid connection through an ammeter connected as indicated in Figure 3. With the solid ground, the phase $A$ capacitance is short-circuited, the voltage on phase $B$ capacitance becomes $E_{AB}$ and that on phase $C$ capacitance becomes $E_{AC}$, shown in Figure 2B. The power voltage to ground on the unfaulted phase capacitances thus becomes phase-to-phase voltage or 1.73 times the normal phase-to-neutral voltage.

When one conductor is grounded, the neutrals of Y-connected equipment on the bus are no longer at ground potential. In the case considered, the voltage between the equipment neutrals and ground becomes $E_{04}$. By the connection of generator neutral potential transformers as shown in Figure 1, the appearance of a neutral voltage to ground is used at Holtwood to detect the presence of a ground fault. In the majority of cases, the operation of the ground detector relay is the only indication to the station operator that something is wrong, because the equipment continues to function otherwise in a normal manner. The characteristics of this type of fault detector are analyzed in Appendix II.

If insulation should fail on phase $A$, it probably will occur when $E_{04}$ is at or near its peak value. Phase $A$ capacitance will be short-circuited, its charge sending a surge through the fault. The voltages on the two unfaulted phase capacitances suddenly change from the respective phase-to-neutral values to the higher phase-to-phase values. These capacitances are charged through the fault by the higher voltages. The magnitude of the surge through the fault depends upon the system operating voltage and the value of the phase capacitances. It is therefore important, when investigating arcing grounds, to know the system voltage, which can be measured directly, and the phase-to-ground capacitances or capacitive reactances. A method for measuring the latter is given in Appendix I.

**Table I. Frequencies at Which Resonance Phenomena Appear on Representative 60-Cycle Units in Holtwood Station**

| Unit | Rating | Resonant Frequencies, Kc |
|---|---|---|
| No. 15 transformer | 3 phase, 13.2 to 73 kv with taps, 33,750 kva | 16, 18, 46, 55, 60 |
| No. 12 transformer | 3 phase, 13.2 to 73 kv with taps, 20,000 kva | 15.5, 21.5, 26 |
| No. 10 waterwheel generator | 3 phase, 13.2 kv, 94.7 rpm, 15,000 kva | 1.6, 10 |
| No. 15 steam turbine generator | 3 phase, 13.2 kv, 1,800 rpm, 12,500 kva | 3.8, 33, 62 |
| No. 62 frequency changer | 3 phase, 60-cycle, 13.2 kv, 300 rpm, 7,140 kva | 4.2, 21.2, 50 |

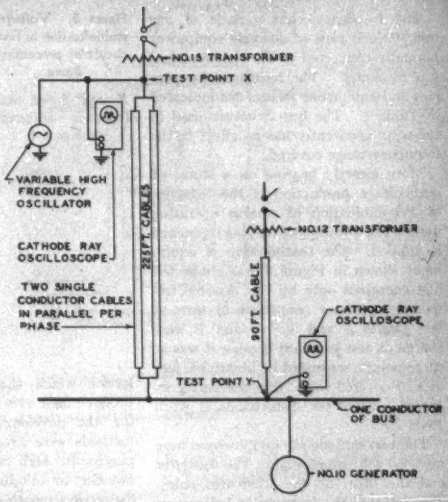


**Figure 4. Connections for high-frequency measurements on bus**

Distance between test points $X$ and $Y$ is about 300 circuit feet

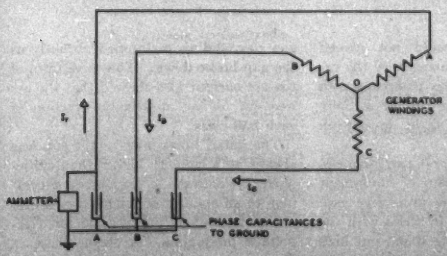


**Figure 3. Circuit conditions when A-phase bus conductor is grounded through an ammeter**

## Standing Wave Characteristics of Operating Equipment

A station bus and its connected equipment do not have concentrated capacitances to ground as shown in the simplified equivalent circuit of Figure 1. Each element of bus and equipment has its inherent distributed capacitance and inductance with consequent characteristic frequencies at which resonance phenomena can occur. With the individual components of the system connected in parallel for operation, there are a number of such resonance frequencies at which oscillations might be initiated by an arcing ground. The phenomena are of interest because standing waves at the resonance frequencies can cause uneven distribution of voltage to ground along the bus system. A study of standing waves on such a system gives some insight into the way in which wave phenomena can cause overvoltages.

Standing waves on the Holtwood bus were investigated by observing changes of impedance of each type of equipment, singly and in combination, as the frequency of a voltage applied between one phase conductor and ground was varied between 100 and 100,000 cycles per second. Except for the high-frequency voltage, the equipment was not energized. The work was done expeditiously by utilizing a chart-drawing transmission line fault locator.[11] The fault locator charts were obtained quickly and on them the resonance frequencies were at once apparent.

The frequency characteristic of one unit of each type of 60-cycle equipment normally connected to the Holtwood bus was measured. The resonance frequencies and equipment ratings are indicated in Table I. The bus structure used in the tests apparently has no effect in the frequency range covered.

More directly bearing on a study of overvoltage production is the behavior of a combination of station operating units when a voltage of varying frequency is applied. The combination of equipment shown in Figure 4 was connected and energized only by the variable frequency oscillator connected in turn at test points *X* and *Y*. *X* and *Y* were chosen as test locations because it was at these points, separated by about 300 feet of lead covered cable, that the faults occurred causing the disturbance of April 1942.

The two cathode ray oscilloscopes were used as voltmeters, one at the oscillator and the other at the other test point. The ratio of the instrument indications was a measure of the voltage rise due to standing waves.

Figure 5 shows that voltage multiplication up to $2^3/_4$ times was measured with the test arrangement. The resonance frequencies for the combination were those of the connected individual units. It should be noted that the maximum voltage multiplication within the measurement range occurs at the relatively high frequencies of 50,000 and 100,000 cycles per second. These tests indicate that no voltage higher than three times normal is to be expected from standing waves at any natural frequency of the system, a point substantiated by the arcing tests described later.

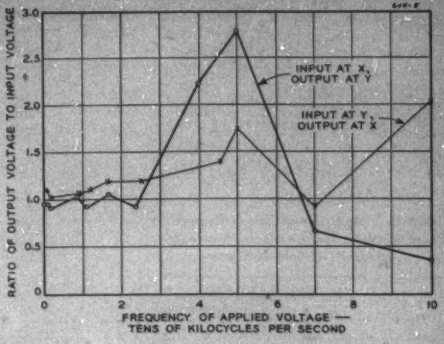


**Figure 5. Voltage multiplication in test circuit of preceding figure**

*X* and *Y* are test locations indicated in Figure 4

## Characteristics of Arc Gaps

The ways in which overvoltages can be developed on an ungrounded system have been described in great detail in the technical literature. A few of the many papers on the subject are listed in the references of this paper. Simply stated, overvoltages can be built up by an arcing ground if the arc is made to restrike each half cycle at progressively higher voltages. If this restriking can be made to occur at the natural period of the system, the resulting voltages theoretically will be higher than if the restriking phenomenon occurs at power frequency.[1]

Before the arcing tests on the Holtwood bus were undertaken, it was necessary to study the characteristics of various types of arc gaps and to develop one having as nearly as possible the behavior which theory indicates should produce high overvoltages. While making the development, highly artificial methods were avoided such as are employed in high speed circuit breaker practice to obtain progressively higher dielectric strength in the arc gap at each restrike, because such conditions are unlikely to occur in the field.

Three-phase equipment was not available for the developmental work to supply the same arc voltage and current as would be produced in the field. However, conditions were approximated quite well with the single phase circuit shown in Figure 6. The maximum voltage that could be used was limited to 9.6 kv by the rating of the capacitors, as compared to 13.2 kv on the tested bus. The breakdown of the tested gaps during the developmental period could not exceed $^1/_3$ of 9.6 kv = 4.8 kv because of the capacitor limitation. This compares with 13.2/1.73 = 7.6 kv, the voltage initially across any fault that might develop on the actual bus.

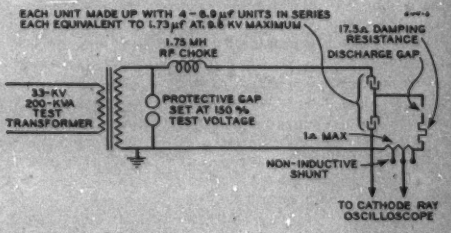
EACH UNIT MADE UP WITH 4 - 8.0 μf UNITS IN SERIES
EACH EQUIVALENT TO 1.73 μf AT 9.6 KV MAXIMUM
17.5Ω DAMPING RESISTANCE
1.75 MH RF CHOKE
DISCHARGE GAP
33-KV 200-KVA TEST TRANSFORMER
PROTECTIVE GAP SET AT 150 % TEST VOLTAGE
1Ω MAX
NON-INDUCTIVE SHUNT
TO CATHODE RAY OSCILLOSCOPE

**Figure 6. Arrangement for preliminary tests of discharge gaps, oscillograph shunt, and instrument transformers used in the arcing ground tests**

In the circuit of Figure 6, two other elements for the protection of equipment were added besides the protective gap. The 17.5-ohm resistor in series with the arc gap was included to damp out high frequency oscillations which overheated conductors in the early stages of the work. The choke coil was placed to keep stray high frequency currents from the transformer. The noninductive shunt of straight carbon rod provided the voltage drop for making the wave form of the arc current appear on the oscilloscope. Besides being used for the gap development, the circuit of Figure 6 was used to ensure that the instrument transformers used in the field tests correctly reproduced wave forms within the frequency capabilities of the oscilloscopes and oscillograph used.

The first type of gap studied was a simple air gap of the form shown in Figure 7. It was tested in the circuit of Figure 6 where it exhibited a restriking characteristic. Each half cycle the voltage on the gap rose and then dropped abruptly as the gap broke down. The wave form of the arc current also showed that the arc was out for an appreciable fraction of each half-cycle.

The initial breakdown of the gap was always at a voltage higher than subsequent breakdowns, a characteristic common to all open, fixed-length arcs in still air, and which is unfavorable for overvoltage production. A strong blast of

air blown across the gap maintained the breakdown at its high initial value and also caused several restrikes each half cycle. Since this artificial condition is not normal in the field, the air blast was not used for any bus tests.

The next type of gap tested is shown in Figure 8 and consists of a porcelain enclosed and filled gap designed to produce in a controlled way an arcing breakdown similar to that occurring when a porcelain insulator fails. The large electrodes, 1-inch diameter, were used to simulate the large metal cap and pin of an insulator which do not overheat quickly when an arc is formed. The length of this enclosed gap was set by trial to give the desired breakdown value with the gap space filled with porcelain granules. While this adjustment was being made, a high resistance was connected in series with the gap to limit the current to a small value. When the gap was placed in the test circuit of Figure 6, the arc was erratic, sometimes restriking a number of times each half-cycle. After a few cycles the porcelain granules fused and the gap practically short-circuited. The number of cycles that the arc persisted depended upon the power liberated in the arc. This gap, like the simple open gap, did not restrike at progressively higher voltages but acted more as a voltage limiter.

A third type of gap which was thought to produce more severe test conditions was constructed by converting the simple gap of Figure 7 into a self-lengthening gap. One of the cap screw electrodes was drilled axially to hold a small fusible electrode, a number 22 gauge wire. The position of the wire was adjusted with respect to the undrilled electrode, and held fast with a set screw, to give any desired initial breakdown. After an arc formed on the self-lengthening gap, the burning of the wire during each half-cycle of power current increased the length of the arc gap, permitting the restrike voltage to rise progressively. Figure 9 shows the appearance of the self-lengthening gap, before and after a test. As described later, this type of gap produced higher voltages than the fixed length gaps when used for arcing grounds on the Holtwood bus, but still the voltages were not nearly as high as published theory indicates.

The final design of gap, which produced the most severe arcing conditions in the bus tests, was an enclosed self-lengthening gap obtained by modifying the enclosed gap of Figure 8. The porcelain tube having 1-inch inside diameter was replaced with one having 3/16-inch bore. Iron electrodes were gasket-sealed into this tube. The air gap was made self-lengthening by providing one of the iron electrodes with a projecting small copper wire to be burned away by the arc. The small sealed space occupied by the arc and the progressive arc lengthening were especially favorable to overvoltage production.

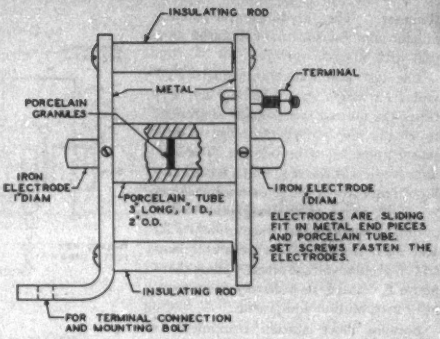
INSULATING ROD
TERMINAL
METAL
PORCELAIN GRANULES
IRON ELECTRODE 1" DIAM
PORCELAIN TUBE 3" LONG, 1" I.D., 2" O.D.
IRON ELECTRODE 1" DIAM
ELECTRODES ARE SLIDING FIT IN METAL END PIECES AND PORCELAIN TUBE. SET SCREWS FASTEN THE ELECTRODES.
INSULATING ROD
FOR TERMINAL CONNECTION AND MOUNTING BOLT

Figure 8. Porcelain enclosed and filled arc gap

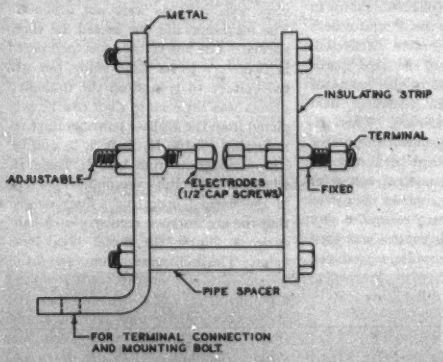


Figure 7. Open arc gap

## Method of Making Arcing Ground Tests on the Station Bus

The station equipment which was used for the high frequency measurements was also used for the high voltage arcing ground tests. Due to system operating conditions, number 9 generator was substituted for number 10 generator in the latter tests; the two machines are essentially duplicates. Figure 10 gives the connections for the arcing ground tests. This test arrangement produced a charging current of 2.5 amperes through a solid ground as compared to a current of about 9.1 amperes produced by the entire bus system used in normal operation. The capacitive reactance to ground of one phase conductor of the test arrangement was thus about $9.1/2.5 \times 2{,}500 = 9{,}100$ ohms as compared to 2,500 ohms for operating conditions.

The section of the bus indicated in Figure 10 was that on which occurred one of the faults of April 1942 and power transformer $T1$ was number 15 transformer where the other fault occurred. The fuse and gaps shown in the arc gap circuit of Figure 10 were included as safety precautions. Another safety measure was the insulating transformer between the oscillograph and the arc gap circuit. It was especially developed for the work, tested and modified until it had insulation adequate to protect the oscillograph operator against mishaps and it reproduced complex wave forms faithfully on the oscillograph.

The klydonograph, a photographic surge crest voltage recorder producing Lichtenberg figures, was connected to the bus through a 3-pole capacitive poten-

tiometer. The klydonograph–potentiometer combination was calibrated as a unit with 60-cycle voltage.

The test potential transformers *PT*1 and *PT*2 had a rating of 34.5 kv, $4\frac{1}{2}$ times the normal bus voltage to ground, to ensure the proper recording of any power frequency overvoltages. The klydonograph was relied upon to record any high frequency or surge overvoltages beyond the range of the magnetic oscillograph. The potential transformers *PT*3 and *PT*4, measuring the generator neutral-to-ground voltage and the phase *A*-to-phase *B* voltage, respectively, were regularly used station equipment.

Because more station equipment is normally connected to the bus than was the case during the tests, one of the tests was performed with a 3-phase Y-connected neutral-grounded bank of capacitors connected to the bus at test location *Y*. Each of the three legs of the bank had a nominal rating of 7.2 kv, 2.3 microfarads. This capacitance, with the capacitance to ground of 0.29 microfarad per phase of the station equipment, gave a phase-to-ground capacitance of around 2.6 microfarads for the test. This value is more than twice as much as the 1.06 microfarad of the equipment normally connected.

## Arcing Test Procedure

Preliminary to each test, the arc gap for the test was adjusted and tested in a laboratory low-current circuit to have the desired initial breakdown value.

After the equipment was connected for a test as shown in Figure 10, the disconnecting switch in the arc gap circuit was left open and the generator voltage was then set at the chosen test value. Following this, the generator was left running at normal speed without field excitation. The disconnecting switch was then closed, connecting the arc gap circuit to the phase *A* conductor. The gap in each case was previously adjusted to 90 per cent of the preset generator phase-to-neutral voltage.

When the recording instruments were ready, the field switch of the generator was closed. This operation, in addition to exciting the generator field, also lit a small lamp, signaling the oscillograph operator to start that instrument. The generator required about 2 or 3 seconds to attain its preset voltage. When the arc gap flashed over, the voltmeter shown in Figure 10 connected to the generator neutral potential transformer, deflected. When making tests with the fixed length gaps, this was a signal to the generator operator to open the generator field breaker to extinguish the arc. When using the self-lengthening gaps, the operator delayed opening the field breaker for a few seconds after the neutral voltmeter first deflected to allow time for the arc to extinguish itself by lengthening the gap. This method of circuit control was used to ensure that any overvoltage produced during a test was due to the arcing ground alone and not due to any switching surges.

A—Before test

B—After test

**Figure 9. High-speed self-lengthening arc gap**

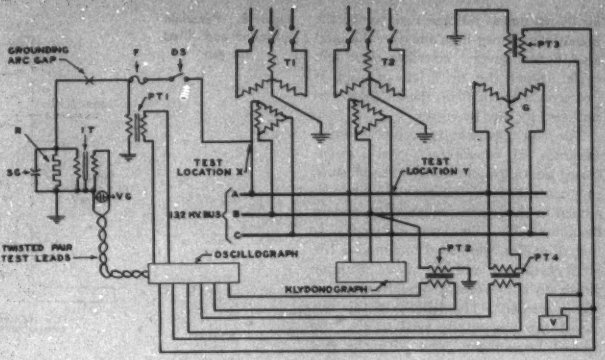


**Figure 10. Connections for arcing ground tests on Holtwood 60-cycle bus**

SG = 1/32-inch spill gap
R = 0.3-ohm rod resistor
IT = insulating transformer
VG = safety vacuum gap
PT1, PT2 = 34,500- to 115-volt instrument transformers
PT3, PT4 = 13,200- to 110-volt instrument transformers
F = 15,000-volt 100-ampere fuse
DS = disconnect switch
T1, T2 = power transformers
G = water wheel generator
V = generator neutral voltmeter

## Results of Arcing Tests With Fixed Length Gaps

Because of the widespread belief that an arcing ground quite easily will produce dangerously high overvoltages on an ungrounded bus system, the tests on the Holtwood bus were begun with reduced bus voltage and a simple open fixed-length gap. As shown in Table II, test 1, very high voltages were not produced. The maximum did not exceed 2.3 times normal. The bus voltage was then raised in two steps to its rated value, but still the voltage to ground on the unfaulted phases was little more than can be predicted from the 3-phase power voltage relationship (Table II, tests 2, 3, and 6). The oscillogram from test 1, Table II, when the test voltage was only 50 per cent of the normal operating value, showed that the arc restruck regularly each half-cycle at almost the initial breakdown value. The oscillograms from tests 3 and 6, Table II, when the test voltage was the full operating value, showed that the arc always restruck at a voltage substantially less than the initial breakdown value. The change in the restriking phenomenon with increase of test voltage was probably due to the greater arc energy in the latter tests making the gap more difficult to deionize.

Tests 4 and 5 with the porcelain filled gap showed that an arcing ground produced by the failure of a porcelain insulator is not likely to produce high transient overvoltages. The oscillograms

Table II. Voltages Produced by Arcing Grounds With Fixed Length Gaps

| Test | Generator Voltage Setting (Per Cent Normal) | Gap Type | Maximum Phase-to-Ground Voltages (Per Cent Phase-to-Neutral Voltage) From Oscillograph B Phase | From Klydonograph B Phase | From Klydonograph C Phase | Total Duration of Arcing, Sec |
|---|---|---|---|---|---|---|
| 1 | 50 | Open | 212 | 236 | 177 | 1.5 |
| 2 | 75 | Open | 186 | 190 | 176 | 1.3 |
| 3 | 100 | Open | 183 | 180 | 150 | 1.42 |
| 4 | 75 | Porcelain filled | 187 | 156 | 145 | 0.01– |
| 5 | 100 | Porcelain filled | 200 | 233 | 168 | 0.01– |
| 6* | 100 | Open | 192 | 190 | 190 | 1.42 |

*20 ohms on secondary of neutral potential transformer.

Arc was extinguished in these tests by opening generator field circuit.

Table III. Voltages Produced by Arcing Grounds With Self-Lengthening Gaps

| Test | Generator Voltage Setting (Per Cent Normal) | Gap Type | Wire in Fusible Electrode | Maximum Phase-to-Ground Voltages (Per Cent Phase-to-Neutral Voltage) From Oscillograph B Phase | From Klydonograph B Phase | From Klydonograph C Phase | Total Duration of Arc, Sec |
|---|---|---|---|---|---|---|---|
| 1 | 50 | Open | No. 22 Nichrome | 227 | 224 | 268 | 0.8+ |
| 2 | 50 | Open | No. 22 copper | 233 | 209 | 145 | 2.35 |
| 3 | 50 | Enclosed | No. 22 copper | 283 | 220 | 189 | 1.05 |
| 4 | 50 | Enclosed | No. 30 copper | 279 | 232 | 212 | 0.08 |
| 5* | 40 | Open | No. 22 copper | 301 | 280 | 256 | 0.11 |

*2.3-microfarad capacitor added between each phase conductor and ground.

Arc extinguished itself in these tests, because of elongation of gap, before the generator field circuit was opened.

showed that the voltage across the gap was very low after the initial strike.

For each of the tests in this group, the fixed length of the gap acted as a limiter to prevent the recovery voltage across the gap from rising above the initial breakdown value. Consequently, the voltages from the unfaulted phases to ground did not much exceed 1.73 times the normal phase-to-neutral voltage in any of these tests.

Figure 11. Oscillogram from test with enclosed self-lengthening gap

Test 4, Table III

## Results of Arcing Tests With Self-Lengthening Gaps

After showing that high overvoltages do not accompany arcing grounds on gaps having fixed length, due to the limiting effect of the gap on the recovery voltage, further testing was done with self-lengthening gaps. The results of these latter tests are given in Table III.

Nichrome wire, size 22, was used in the first test of this group to ensure that the arc would persist long enough for overvoltage to build up, if there were any such tendency present. No very high overvoltage developed. The second test, using faster fusing copper wire, gave about the same value of overvoltage as the first test, with a total arcing time of about $2\frac{1}{4}$ seconds. Both tests were made with open gaps.

Tests 3 and 4, where the enclosed self-lengthening gap was used, showed higher overvoltages than the preceding tests, but not more than about 2.8 times normal phase-to-neutral voltage. The type of gap used for this test probably produced as severe an arcing condition as is likely to occur on the station bus under operating conditions. Most likely, an arcing ground on the bus will be formed across a gap having fixed length, where the voltage to ground will not rise much above two times normal due to the limiting action of the gap.

Figure 11 is the oscillogram obtained during test 4 of Table III for which an enclosed self-lengthening gap was used. The oscillogram shows that the arcing ground persisted for only a fraction of each cycle of power frequency, but that each strike produced a highly damped train of oscillations having a frequency of about 1,140 cycles per second. Table I shows that the lowest natural frequency for any equipment on the unenergized bus is 1,600 cycles per second, which is for the waterwheel generator with no field excitation. It is probable that the lower natural frequency obtained under arcing conditions is due to generator field excitation, which changes the inductance of the generator windings.

In test 4 the arc struck only 11 times because of the small size (number 30) of the fusible electrode used in the gap; the behavior is typical except that the arc struck more frequently during the other tests of this group.

The highest instantaneous value of

Figure 12. Test with capacitors connected to bus

Oscillogram from test 5, Table III

**Figure 13. Arc strikes on only one polarity of voltage**

Section of oscillogram from test 2, Table III

arc current recorded on the oscillogram of Figure 11 is 44 amperes, which occurred during the next to last arc strike.

The frequency of oscillations in the arc current and in the several recorded voltages was mostly between 1,080 and 1,200 cycles per second, sometimes around 1,600 cycles per second. In test 5, Table III, a capacitance of 2.3 microfarads was added between each phase conductor and ground. During this test the oscillations had four distinct frequencies, being about 460, 2,700, 4,200 and 6,780 cycles per second. Figure 12 is the oscillogram obtained during this test.

## Discussion

Figure 11 shows the characteristic behavior of the 60-cycle voltages to ground after the arc remained extinguished: the almost completely displaced wave, producing a recovery voltage two times normal, and its slow return to normal. The phenomenon is caused by the relatively slow re-establishment of normal charge distribution on the three bus capacitances to ground shown in Figure 1. It is the retention of charge by these capacitances, added to the dynamic power voltages, that causes the recovery voltage wave to be two times normal by being completely displaced. Theoretically this can produce overvoltages to ground on the unfaulted phases as high as 2.73 times normal, because at the time of arc extinction, the unfaulted phase capacitances can remain charged to 1.73 times the normal phase-to-neutral voltage, to which may add the generated system phase-to-neutral voltage. By comparison, in the tests with the fixed length gaps, the recovery voltage across the arc gap was always limited to the normal crest phase-to-neutral value or less and the voltages measured on the unfaulted phases did not greatly exceed 1.73 times normal phase-to-neutral voltage.

Superimposed on the power frequency effects just described are the natural frequency transients, of which those shown in Figure 11 are typical. In addition to raising the *B* phase to ground voltage, they also raised the phase-to-phase voltage as shown in the bottom record of Figure 11. In this case the *A*-phase to *B*-phase voltage was raised a maximum of 1.56 times its normal value.

Figure 13 is a section of the oscillogram obtained during test 2 of Table III. It shows a very interesting phenomenon. The arc was quite unsteady, missing a few cycles occasionally as shown in Figure 13, then it restruck regularly on only one polarity of voltage. The single polarity arcing continued for 51 cycles, then missed a cycle and finally struck one more time. This phenomenon might have been caused by the rounded shape of one electrode of the arc gap and pointed form of the other. However, this explanation is not entirely satisfactory because none of the other tests with the self-lengthening gaps exhibited this effect even though the electrode shapes were practically the same in all tests. Repeated restriking of an arcing ground on only one polarity of voltage has not been previously reported in any of the technical literature consulted, although P. A. Jeanne[9] has reported a similar phenomenon of a few cycles of arcing at one polarity, changing to a few cycles of arcing at opposite polarity.

In the arc current record of Figure 12 there is evidence of arc extinction and restriking at the lowest natural frequency of the system, about 460 cycles per second. However, it is significant that the voltage across the arc gap did not rise appreciably prior to each restrike, apparently due to the short time available for deionization, It is doubtful if an arcing ground, either open or confined, on an actual bus will be subjected to high speed deionization, because highly artificial means, such as air or oil blast, must be employed for high speed circuit interruption. It thus appears that restriking of an arcing ground at progressively higher voltages and at resonant frequency is highly improbable on an actual bus system.

Within the frequency limitations of the electromagnetic oscillograph, that is, for voltages having a frequency less than about 3,500 cycles per second, the oscillograph is a more accurate instrument than the klydonograph. The klydonograph excels where the voltages are of high frequency or steep wave front. It will be noted in Tables II and III that the oscillograph usually indicated a higher overvoltage than did the klydonograph. This is interpreted to mean that steep-front surge voltages and voltages with a frequency above 3,500 cycles per second play no appreciable part in the production of overvoltage under the test conditions.

The klydonograph measurements in Tables II and III show that the maximum voltage to ground on the two unfaulted phases of the bus consistently are not equal when an arcing ground exists. The reason for this is indicated on the oscillogram of Figure 11, which can be taken as typical, where the arcing persists at most for only a third of a 60-cycle half wave. In this figure and also in the bottom trace of Figure 13, it will be seen that the voltage oscillations produced by the arc begin before or at the peak of *A*-phase to *B*-phase voltage. When *A* phase is grounded by an arc, the *A*-phase to *B*-phase voltage is the same as *B*-phase to ground voltage except for the arc drop, which is comparatively small. Figure 2 shows the phase relationships when *A*-phase bus conductor is grounded. With respect to the grounded conductor (*A* phase), voltage $E_{AB}$ leads $E_{AC}$ by 60°. Figure 14 shows the appearance of two sinusoidal half waves of power voltage having this relationship. If the arcing

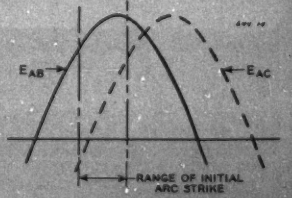


**Figure 14. Period during which arcing transients begin on the phase-to-ground voltages of the unfaulted phases**

Current and voltage relations when *A*-phase bus is grounded

transient occurs anywhere in the range indicated on Figure 14, it will be superimposed simultaneously on an instantaneous value of $E_{AB}$ higher than the corresponding instantaneous value of $E_{AC}$. This usually makes the voltage to ground on $B$-phase conductor higher than that on $C$ phase, although erratic arc strikes at other phase positions may alter this relationship. Such an unusual condition occurred in test 2 (Table III), where the highest transient voltages during the test occurred when the arc struck for voltages of only one polarity.

## Summary and Conclusions

As stated previously, the following apply only to arcing grounds on normally ungrounded station busses and not to switching phenomena or effects of surges on extensive systems.

1. Arcing grounds on the tested station bus did not produce voltages to ground exceeding three times the normal crest phase-to-neutral voltage. Higher overvoltages did not materialize even though conditions in some of the tests were as severe as any likely to occur under operating conditions.

2. It has been shown in previously published literature that extremely high voltages can be produced by arcing grounds when the arcs quench and restrike at progressively higher voltages and at system natural frequency. It has been suggested that a ground fault in a pothead, cable, or other arc confining piece of equipment might provide especially favorable conditions.[12] As far as is known, build-up of voltage in excess of about three times the normal phase-to-neutral value has yet to be measured on an actual bus system operating at 13 kv or less. The study of arc gaps described in this report and operating experience published elsewhere, show that very rapid quenching of an arcing ground is not likely to be accomplished by any combination of circumstances which might occur on a station bus and associated equipment.

3. The maximum voltages to ground on the unfaulted phases of a three-phase bus are not equal under most arcing ground conditions.

4. Arcing grounds occur sometimes on only one polarity of voltage.

5. The tests revealed arcing transients which raise the phase-to-phase bus voltages as high as 1.74 times normal. The frequency of these transients was found to be as high as 6,780 cycles per second. Transients of this character may cause abnormal voltage stresses on the turn insulation of machines.

6. The faults of April 1942 on the ungrounded Holtwood bus very probably were caused by failure of defective porcelain insulators in quick succession because very careful inspection of the bus after the disturbance disclosed a number of them with minute cracks in the porcelain. It is probable that the trouble was initiated by the failure of one porcelain insulator, causing bus voltages to ground on the other phases between 1.73 and 3 times normal. This overvoltage then probably caused failure of one or more additional defective insulators. On an ungrounded bus system, it is particularly important that the insulation of the bus and of associated equipment be maintained at its initial strength and be tested periodically with the most sensitive means available for detecting defects. It is believed that many insulation breakdowns on ungrounded busses which have been attributed to voltage build-up, were probably caused by reduced insulation which might have been found by modern testing means.

7. Insulation should be provided on ungrounded busses and connected equipment capable of withstanding voltages to ground in excess of three times the normal phase-to-neutral value. Also, the turn insulation on machine windings must withstand high frequency voltages which accompany arcing grounds. How severe these latter voltages are, has not been determined. With these conditions met, advantage can be taken of the operating features which an ungrounded bus provides, and it is believed that no great concern need be felt that unlimited high voltages will be produced by an occasional ground fault.

8. A device for warning of impaired insulation on an ungrounded bus system and operated by the appearance of neutral-to-ground voltage is often inoperative until the insulation is broken down completely. In spite of this limitation, the device has proved useful in operation. A method is included in the paper for easily determining the sensitivity of a neutral voltage ground detector in any given installation.

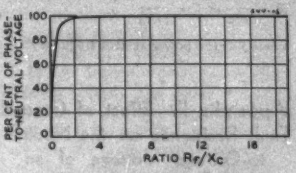


**Figure 16. Variation of voltage across fault $E_f$ for various ratios of $R_f/X_c$**

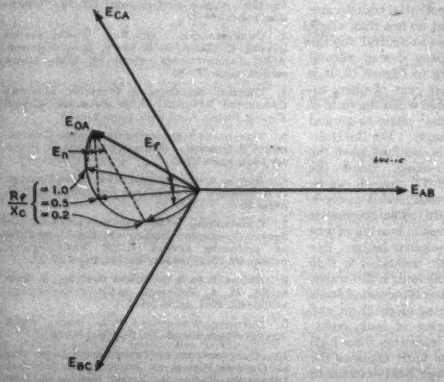


**Figure 15. Vector relation between voltage across fault $E_f$ and generator neutral voltage to ground $E_n$ for three ratios of $R_f/X_c$**

## Appendix I. Determination of Phase-to-Ground Capacitance of an Ungrounded 3-Phase Bus

The equivalent circuit of an ungrounded bus and connected apparatus is shown in Figure 1. Each item of equipment connected to the bus system, whether transformer, cable, bus, or rotating machine, contributes its share to the admittance of each phase conductor to ground. When insulation is unimpaired, the corresponding impedances are almost pure capacitive reactances which can be taken as lumped constants for purposes of analysis.

The capacitive reactances to ground of the bus system can be measured in the field by solidly grounding one phase of the system through an ammeter. When this is done, one of the bus-to-ground capacitances is short-circuited and the two ungrounded capacitances pass current through the ammeter as shown in Figure 3. With the directions of current flow as assumed in Figure 3, the vector relations of the currents are as shown in Figure 2B.

$$I_T = I_B \cos 30° + I_C \cos 30°$$

The charging currents of phase-$B$ and phase-$C$ bus conductors are numerically equal:

$$I_{sc} = I_B = I_C$$

Therefore

$$I_T = I_{sc} \cos 30° + I_{sc} \cos 30°$$

$$= 2I_{sc} \times 0.866 = 1.73 I_{sc}$$

or

$$I_{sc} = \frac{I_T}{1.73}$$

The capacitive reactance of one phase conductor to ground is found from the phase-

to-phase voltage $E$ and the grounding ammeter reading $I_T$:

$$X_c = \frac{E}{I_{3c}} = \frac{E}{I_T/1.73} = \frac{1.73E}{I_T}$$

The capacitance can then be found by solving for $C$ in the equation

$$X_c = \frac{1}{2\pi fC} \text{ or } C = \frac{1}{2\pi fX_c}$$

where $f$ is the power system frequency.

## Appendix II. Effect of Ground Fault Resistance on the Neutral-to-Ground Voltage of an Ungrounded 3-Phase Bus

Fault detection with a generator neutral potential transformer requires a shift in the neutral potential for its indications. An impairment of bus or equipment insulation to ground is equivalent to a shunt across the capacitance-to-ground of the phase conductor affected. A ground fault with a given resistance will have more effect on neutral potential shift if the capacitance to ground is small than if it is large. Or expressed in a more practical way, because the capacitive reactance is the quantity determined directly from a grounding ammeter test, the greater the capacitive reactance to ground of a system, the more effect a given value of fault resistance will have on neutral shift. The analysis has been made on a unit basis to

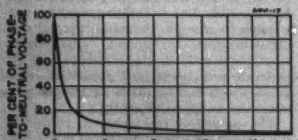


**Figure 17. Variation of generator neutral voltage to ground $E_n$ for various ratios of $R_f/X_c$**

make the results applicable to any field condition where the capacitive reactance to ground of the bus can be measured. The steps in the analysis are as follows:

(a). The currents and voltages in Figures 2 and 3 are directly proportional to the system phase-to-phase voltage. In the calculations, 1,000 volts was used as the unit base for this voltage. Under these conditions, the phase-to-neutral voltage is 1,000/-1.73 = 577 volts.

(b). On a unit basis, the capacitive reactance to ground of each phase conductor was taken as $X_c$ = 1,000 ohms.

(c). A bus insulation fault is equivalent to a resistance shunting the capacitive reactance to ground of the faulted phase conductor. Different values of fault resistance $R_f$ were assumed in succession, ranging from one megohm to zero. This gave ratios of $R_f/X_c$ ranging from 1,000 to zero. Each of the following steps was carried through separately for each assumed value of $R_f$ faulting the phase-$A$ bus conductor.

(d). The parallel circuit of the fault resistance $R_f$ shunting the phase-to-ground capacitive reactance $X_c$ was transformed into its equivalent series circuit, giving $Z_a$.

(e). The current through the $X_c$ of each unfaulted phase is the corresponding phase voltage divided by $X_c + Z_a$, giving $Ia$ and $Ic$, calculated separately.

(f). The current in the circuit composed of the faulted phase capacitance and fault resistance in parallel is $Ir = Ia + Ic$.

(g). The voltage across the fault is $E_f = IrZ_a$ (Figures 15, 16).

(h). The generator neutral voltage to ground, $E_n$, is the phase-to-neutral voltage of the faulted phase minus the fault voltage or

$$E_n = E_{OA} - E_f \text{ (Figures 15, 17)}$$

(i). The power dissipated in the fault is

$$P_f = \frac{E_f^2}{R_f}$$

The results of the calculations are summarized in Figures 15, 16, and 17. The computations were checked in the laboratory with equivalent circuits having several values of $X_c$. The effect of the generator neutral potential transformers and their secondary burdens has been neglected in the computation because the impedance of each is quite high, varying from one to two megohms, depending upon the applied voltage.

### Discussion

To avoid forced outages and interruption of central station electric service, it is very desirable to obtain notice of any bus insulation defect as soon as possible. At Holtwood the neutral voltage ground detector shown in Figure 1 is used. The alarm did not operate before the flashovers of April 1942 occurred. However, the relay targets were found to have operated after the trouble. Because the alarm did not give an indication until the trouble occurred, the foregoing analysis was made to determine how low the resistance of a fault must be to operate the alarm.

The capacitive reactance to ground of one phase of the Holtwood station bus is about 2,500 ohms. The relay connected to the secondary of a neutral potential transformer must be set to operate at no less than about 30 per cent of the phase-to-neutral voltage to avoid false indications during normal switching. By referring to Figure 17, it is found that about 30 per cent of phase-to-neutral voltage is obtained when the ratio of fault resistance to the phase-to-ground capacitive reactance is unity. For the Holtwood bus, this voltage is obtained when the fault resistance is 2,500 ohms. Before the fault resistance falls to 2,500 ohms, it can be seen in Figure 18 that considerable power is dissipated in the fault. The power is sufficient to cause noticeable heating of any of the usual types of incipient faults. For instance, when the fault resistance is 0.25 megohm, the power in the fault is 230 watts. The relatively large power dissipation leads to extremely rapid heating of the fault and consequent rapid lowering of fault resistance. The very rapid transition from high to low resistance in the fault explains the failure of a neutral voltage fault detector to give warning of impending insulation trouble, and also the general experience of relatively little burning of equipment when faults occur on systems with an ungrounded neutral. In the first case, when rapid heating and failure of the fault begins, the generator neutral voltage is only a few per cent of the value required to trip the fault detector; in the second case, the extremely short time required for complete breakdown of the fault limits the liberated energy to a relatively small value, even though the power level is high for a short interval.

Analysis thus reveals that a neutral voltage relay can detect impaired insulation in a large installation only when the insulation is broken down completely. Because its sensitivity to insulation resistance varies with the amount of equipment in service,

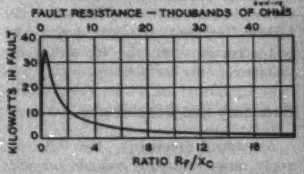


**Figure 18. Variation of power dissipated in a fault with fault resistance for $X_c$ = 2,500 ohms**

the device might warn of impaired insulation prior to complete failure on a small bus system if the bus capacitance to ground and the bus voltage were sufficiently low. It must be recognized that the Holtwood fault detecting devices, even though insensitive to early stages of insulation failure, have proved valuable in service, indicating insulation failures to ground that otherwise would not have been detected promptly.

## References


1. Voltages Induced by Arcing Grounds, J. F. Peters, J. Slepian. AIEE Transactions, volume 42, 1923, pages 478–90.

2. Power-System Transients Caused by Switching and Faults, R. D. Evans, A. C. Monteith, R. L. Witzke. AIEE Transactions, volume 58, 1939, August section, pages 595–94. Discussion, pages 394–7.

3. Overvoltages During Power-System Faults, E. Clarke, S. B. Crary, H. A. Peterson. AIEE Transactions, volume 58, 1939, August section, pages 377–85.

4. Critical Analysis of Rotating Machine Grounding Practice, H. A. Peterson. *General Electric Review*, April 1942, pages 215–20.

5. Merits and Methods of Generator Grounding, S. B. Griscom. *Westinghouse Engineer*, February 1943, pages 33–9.

6. How to Apply Neutral Grounding Devices, A. A. Johnson. *Westinghouse Engineer*, May 1943, pages 66–9.

7. Correlation of System Overvoltages and System-Grounding Impedance, AIEE committee on protective devices. AIEE Transactions, volume 63, 1943, January section, pages 17–24.

8. Arcing Faults in Power Systems, C. Concordia, H. A. Peterson. AIEE Transactions, volume 60, 1941, pages 340–6.

9. Discussion of reference 8, P. A. Jeenes. AIEE Transactions, volume 60, 1941, pages 614–16.

10. Overvoltages on Transmission Lines Due to Ground Faults as Affected by Neutral Impedance, Engineering Report Number 30, Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System, November 15, 1934. EEI publication number D-14, 1936, pages 105–37.

11. Accurate Line Fault Location, J. E. Allen, G. J. Gross. *Electrical World*, July 20, 1935, pages 23–5.

12. Discussion by C. L. Gilkeson. AIEE Transactions, volume 58, 1939, August section, page 395.

# Air-borne Radar for Navigation and Obstacle Detection

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**Synopsis:** The grim uses of radar in war are giving way now to a peacetime role in navigation and obstacle detection. This article discusses the results obtained with military airborne radar as a basis for understanding both the possibilities and the limitations in the application of radar to reduce aviation hazards.

RADAR has been given a great deal of publicity during recent months, and many uses for military operations have been disclosed in technical magazines and newspapers. These publications often included pictures obtained with cathode-ray tube indicators during flight over large American cities and also displayed presentations of enemy territory as viewed on bombing missions. As a result of this publicity and the predictions that have been made for the commercial use of radar, there is probably no single application that catches the public imagination as much as its possible use for navigational aid and obstacle detection in aircraft. Discussions and public expressions of opinions promoting safer navigation are stimulated by aviation accidents such as the Empire State Building disaster and others that have occurred during attempts to land under conditions of obscured vision. Possibly these accidents could have been averted by proper utilization of radar equipment designed to meet obstacle detection requirements. However, there are limitations to present radar performance in that it fails to give the pilot an ideal picture of the area being scanned in its true perspective. But in spite of these limitations, if capable technical effort is applied to the engineering problems involved and these problems are based upon realistic operating requirements and performance, there is every reason to feel that radar will contribute toward safer aircraft navigation and justify the weight of the equipment to be carried.

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## Basic Radar Concepts

The simplest kind of blind navigation system has long been used by pilots of boats operating in rivers and harbors, for they have achieved some measure of success in obstacle detection by using a series of short whistle blasts and then listening for the direction and timing of the echoes.

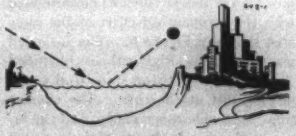


Figure 1. Energy reflected from a smooth surface

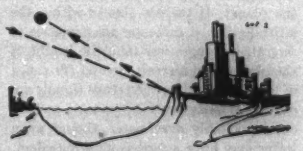


Figure 2. Energy return from a shore line

This example in the detection of reflected energy illustrates the basic principle of radar. For the benefit of the reader who is not familiar with radar, a brief outline of the fundamentals may be helpful.

The purpose of radar is to transmit radio-frequency energy in pulses of high intensity and then to measure the round trip travel time of the reflected energy with sufficient accuracy to establish the range to the obstacle. Following each pulse the transmitter is idle for a relatively long time while a receiving unit is ready to receive the echoes from the preceding pulse. Generally the same antenna is used both for transmission and reception. The finite velocity of electromagnetic waves makes it possible to measure the elapsed time from the transmitted pulse to the received echo as a direct measure of range. This elapsed time is approximately six microseconds for each 1,000 yards of range.

The measurement of range is only a part of the information obtainable with a radar system. Azimuth and elevation angles also can be determined for complete location of a target. This is accomplished by using an antenna that directs the pulsed energy in a narrow beam which may be five degrees wide or less at the half-power points. The position of the target then is determined by the direction of the antenna beam. In the cases where only the bearing angle is of importance, the pattern is narrow in the horizontal plane but broad in the vertical plane for wider angle coverage.

The received signals are displayed on a cathode-ray tube whose sweep is timed from the transmitted pulse, and targets appear as deflections of the sweep or as intensity spots. This display is not like television where an actual picture appears, but the results are interpretable to a trained operator.

To illustrate the types of echo responses from ground targets, consider a source of radio frequency energy radiated in a narrow beam from an aircraft as shown in Figures 1 through 4. If the beam is directed toward the ground at a forward angle, the reflection will be a function of the aspect of the target. The energy which strikes the smooth surface of the lake is reflected away from the source and leaves a dark region on the indicator tube. A shore line, buildings, and normal

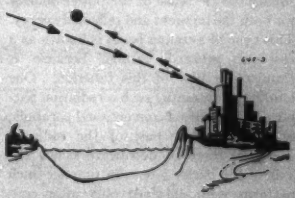


Figure 3. Energy return from structures

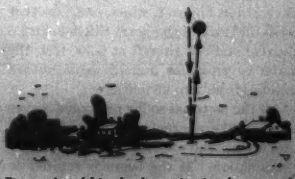


Figure 4. Altitude determination by normal incidence

incidence on the terrain directly below the plane will each provide a strong target echo. A wide beam of uniform intensity directed from the aircraft results in ground illumination and echo response as shown

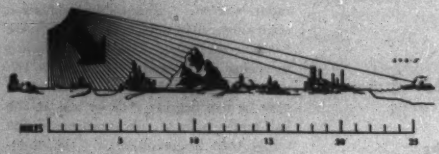



Figure 5. Illumination of generalized topography

in Figures 5 and 6 respectively. These figures also illustrate how it is possible to correlate a radar picture with a relief map of the area.

## Navigation Systems

Navigation systems require that large ground areas be scanned, so antenna patterns of the shape shown in Figure 7 are used to an advantage. Note that the beam is narrow in the horizontal plane in order to obtain azimuth accuracy, while in the vertical plane the beam is broadened to sweep a large area but with a corresponding loss in elevation accuracy. The beam intensity is purposely decreased at angles below the main lobe to obtain uniform signal return at the aircraft for equivalent targets for all ranges to be covered. The shape of the beam is designed to compensate for the inverse square law decrease of the power density for both the incident and reflected energy. This type of antenna beam is known as a cosecant squared pattern because it simulates a plot of this function. One method of obtaining such a radiation pattern is to modify a conventional parabolic reflector so that part of the radiated energy is directed downward below the axis of the major lobe. In practice such patterns were obtained only after considerable experimentation with reflector shapes and types of antenna feeds. An actual plot of a cosecant squared pattern is shown in Figure 8, which indicates that with the peak of the beam tilted down 2.5 degrees and the aircraft at 6,500 feet, the radar coverage for uniform signal return extends from 2 to 20 miles.

All the material so far presented serves to show the character of ground echoes and the method of getting uniform ground illumination. If the beam is rotated or sector scanned and also synchronized with the cathode-ray tube trace of an indicator, a map of the ground relief is presented on the fluorescent screen. Rivers, lakes, shore line, valleys, and mountains will appear in relative direction and range with respect to the aircraft. This type of presentation was used to good advantage during the war on bombing missions when such targets as ships, bridges, and industrial areas were located and destroyed entirely with radar navigation. An example of this type of presentation can be observed in Figure 9, in which the coastal outline and promontories of land are spotted easily. Note how readily this picture can be correlated with the aeronautical chart of the same area shown in Figure 10. The L-shaped promontory at Plymouth is identified clearly, and the tip of Cape Cod is appearing just at the right. The circular rings are 2-mile range marks, and the inner bright ring is the start of the radial sweeps on the scope. The second bright ring is the signal return from the bay directly below and so indicates the height of the plane. If targets appear within the altitude ring, it indicates the presence of aircraft at ranges less than the height of the plane. For aircraft beyond the range of the altitude ring, the return signals are obscured fairly well by ground echoes except possibly over water, though even water may have a serious masking effect. A point of importance here is that an illumination and display which is suitable for navigation would have very little use for obstacle detection.

Figure 10 was taken with the aid of a lightweight low power radar system known as *AN/APS*-10. The essential units of this system are shown in Figure 11, and Figure 12 is a suggested arrangement for installation in a transport plane. The antenna with its parabolic reflector is mounted in a protective housing below the skin-line of the plane to permit complete vision. This housing is built of low loss materials designed for maximum transparency to microwave radio frequencies.

Higher power systems are used to get greater ranges and improved coverage as illustrated by Figures 13 and 14. In the latter figure, the circles are 100-mile marks, and the inlaid map indicates how faithfully the topography is portrayed. Note the shaded portion along the Hudson River caused by the screening hills, and the strong response from the mountainous region beyond.

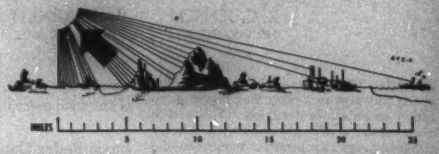



Figure 6. Energy return from ground targets

The technical characteristics of radar sets vary over a wide range depending upon the application. The following tabulation has been prepared to indicate the order of magnitude of the operating characteristics employed in systems such as those used to obtain the preceding scope photographs:

| | |
|---|---|
| Carrier frequency | 3,000–10,000 megacycles |
| Peak power | 10–1,000 kw |
| Pulse frequency | 300–1,000 cycles per second |
| Pulse width | 0.25–2 microseconds |
| Duty cycle | 0.0001—0.001 |
| Maximum range | 50–200 miles |
| Range accuracy | 40–4,000 yards |
| Range resolution | 75–400 yards |
| Azimuth accuracy | 0.5–1 degree |
| Azimuth resolution | 3–6 degrees |
| Receiver | Superheterodyne |
| Intermediate frequency | 30 megacycles |
| Intermediate-frequency band width | 0.5–5 megacycles |
| Minimum detectable signal | 1–10 micromicrowatts |

## Obstacle Detection

It has been stated that a cosecant-squared pattern is unsatisfactory for differentiating between aircraft and ground reflections. This difficulty arises because

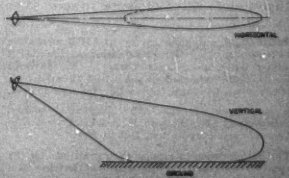



Figure 7. Conventional antenna pattern for navigation radar

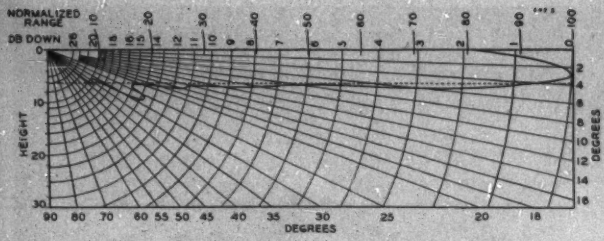



**Figure 8. Actual antenna pattern for navigation radar**

all targets at equivalent range and bearing appear at the same spot in the display whether at ground level or above. The display shows slant ranges from the plane, not actual ground range. Furthermore, the necessarily wide lobe in the vertical direction fails to indicate elevation even though a plane appears in the beam. There is no way for determining elevation unless the beam pattern has essentially the same configuration in the vertical plane as indicated in Figure 7 for the horizontal plane. This requirement demands considerably more performance from the antenna scanning system if the same solid angle is to be illuminated in a given interval of time. The cosecant squared antenna for a system such as *AN/APS*-10 rotates at 30 rpm, while a uniform lobe antenna must scan at many times that speed and simultaneously nod in the vertical plane in order to illuminate the same area. Such systems have been used to obtain a crude television picture of 10 or 12 lines on an indicator that presents azimuth and elevation information. As the antenna rotates, the cathode-ray tube trace sweeps horizontally and also progresses vertically in synchronism with the antenna position.

A second method for scanning a large area with a narrow beam is known as the Palmer Scan. This system employs a pattern which is narrow in both planes. The axis of the reflector is moved in a rectangular path, for example, through a horizontal angle of 75 degrees and a vertical angle of 45 degrees. During this motion the lobe is made to rotate in a rapid conical sweep such that the apex cone angle formed by the axis of the beam is as many as eight times the beam width. This results in illuminating a circular shell around a blank center region, but as the antenna system moves in its rectangular path, the entire area is filled in. A 6-degree beam which scans 21 degrees off the axis of the reflector thus can cover an area of 120 degrees by 90 degrees, while the axis of the reflector follows the borders of a rectangle 45 degrees by 75 degrees.

A third design for wide angle viewing utilizes a spiraling motion of the antenna beam. The angle of advance for the spiral is small enough so that no blank regions appear in the over-all illumination. A solid angle of coverage may be as much as 120 degrees with a lobe width of 5 degrees.

## Present Limitations

These various types of antennas have been discussed briefly to indicate the problems associated with the requirement that enables the system to spot aircraft targets or tall structures and also cover a large area of scanning. They are mechanically complex and require driving mechanisms to spin or slew them at rapid rates so that the scanned area is covered in a few seconds. This is essential if the pilot is to receive scope information comparable with the speed of modern aircraft and avoid collisions. Furthermore, the complexity and fast scanning rates contribute materially toward increased weight of the equipment. In addition, it has been found that beam widths in the order of five degrees are too wide to obtain satisfactory resolution. Lobes of one and two degrees or less are necessary. This demands even faster scanning to cover a given area in a selected interval of time. The point may then be reached where the beam remains on the target for an insufficient length of time to get adequate signal return, and the object is not observed on the indicator. This limit is accepted generally as five pulses on the target during the time of one beam-width

**Figure 9. Radar map of Cape Cod area**

**Figure 10. Chart of Cape Cod area**

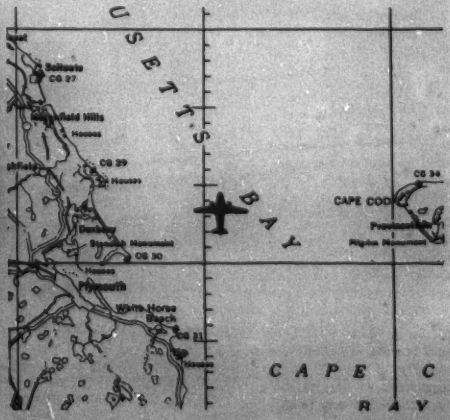


**Figure 11. Air-borne radar system**

1. Antenna Assembly (*AS-154/APS-10*). The antenna or "spinner" may be mounted in a nacelle on the belly of the plane where it revolves in operation to give 360-degree scanning. It can be tilted up and down for critical coverage

2. Transmitter-Receiver (*RT-69/APS-10*). This sealed can is the heart of *AN/APS-10*. In it are the complete self-contained transmitter and receiver. It is pressurized for operation at altitudes up to 30,000 feet

3. Rectifier Power Unit (*PP-111/APS-10*). This compact box is usually mounted out of the way. It converts 115 volts to six different levels of voltage for various functions. They vary from 4,000 volts down to less than 7 volts

4. Trim Control Box (*C-226/APS-10*). This mechanical unit is always mounted near the radar operator. As its name suggests, it is used to adjust the trim of the antenna to compensate for change in the flight altitude of the plane

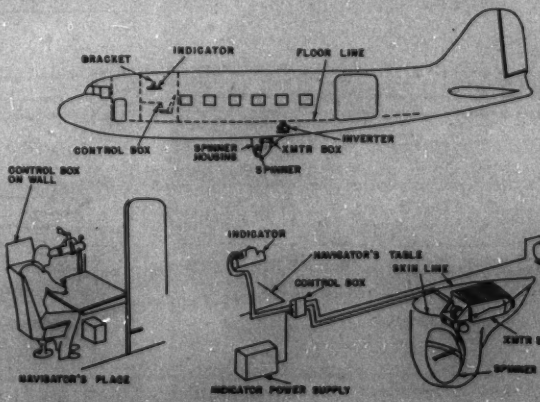
5. Indicator (*ID-99/APS-10*). Here is where the radar information appears. The indicator (PPI) is mounted where it can be studied easily and adjusted quickly. Another one showing identical information may be mounted with the pilot or elsewhere

6. Synchronizer (*SN-17/APS-10*). This small box has most of the manual controls for operation of *AN/APS-10*. It is one of three components in the set which are always mounted within easy reach of the operator

scan. Increasing the pulse rate is the obvious solution, but the pulse repetition rate is dependent upon the maximum operating range, since the return signals should be received before the next pulse is transmitted. Otherwise there would be a confusing indication of targets on the osilloscope. There is also the important consideration of increased average power as pulse rates are accelerated because of the resultant increase in weight with greater power requirements.

The alternative requirement is to reduce the scanned area, thus confining observation to small angles for continuous rapid coverage with the option of selecting other directions for intermittent viewing. The normal operating position would be about the center line of the nose of the airplane.

**Figure 12. Typical installation of air-borne radar**



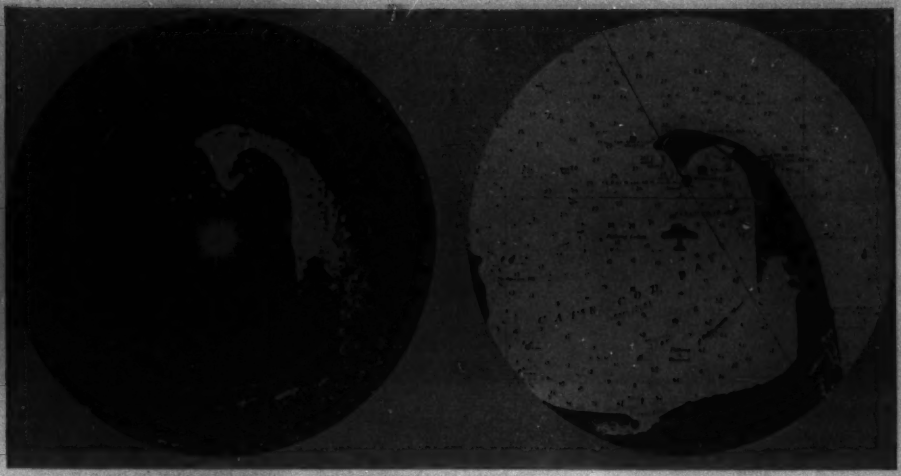


Figure 13. Correlation of radar map with chart

An example of the type of indication that is achieved with a rapid vertical scan antenna using a narrow beam is shown in Figure 15, which plots range against elevation angle. The vertical lines are 2- and 10-mile range marks, while the heavy horizontal trace is an electronic height marker which may be moved by means of a control to line up with a target to indicate elevation. This picture is not indicative of air-borne system performance because it was taken from a high power ground radar; however, it does illustrate the means of presenting target information to obtain height indications. Several aircraft are visible: two at 17 miles and 16,000 feet, very close in range, and a single plane at about 40 miles and 5,000 feet. Two more planes can be observed at about 26 miles. If the picture had been obtained from an air-borne system, the usable range would be reduced considerably because of lower power output. Instead of displaying 50 miles, possibly 20 miles might be the full-scale indication and the ground clutter undoubtedly would extend to the full range. Azimuth information must be read, of course, from a second scope that plots range and azimuth angle, or from a selsyn system that indicates the azimuth position of the antenna. The position of each target would be fixed then with respect to the aircraft.

An interesting photograph that con-

Figure 15. Radar indication of range versus elevation angle

Figure 14. Inlaid radar map of Northeastern States

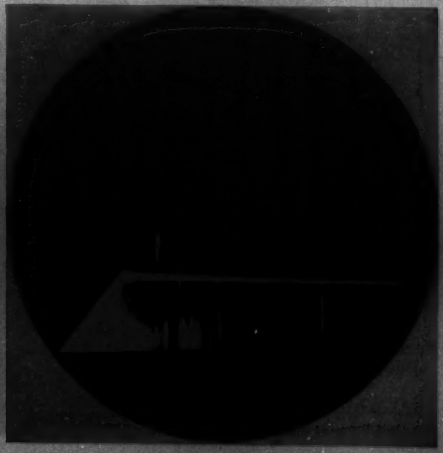


**Figure 16. Radar presentation with polar plot, sector polar plot, and range elevation angle**

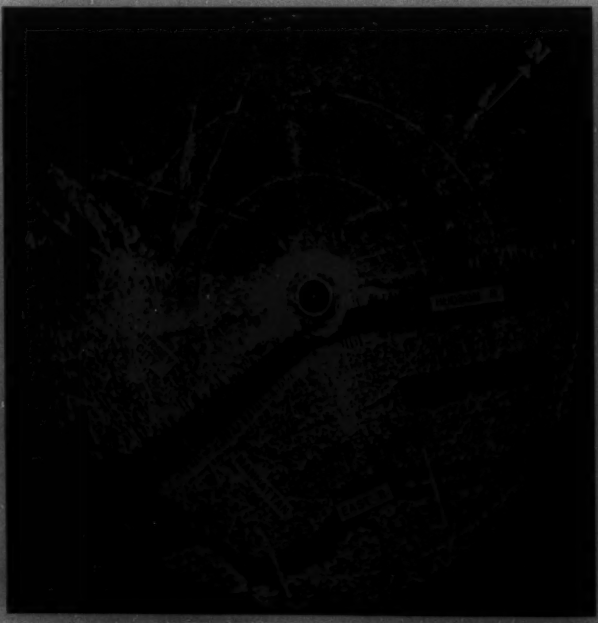
tains both azimuth and elevation information for the same targets is shown in Figure 16. In addition to spotting aircraft, this picture demonstrates the ability of radar to give warning of storm areas. It is apparent that a storm cloud appears at the right and below the target plane in the elevation scope picture, and also can be located in the azimuth presentation.

It should be pointed out that a system which scans only a small sector in the direction of travel to avoid collisions also could obtain navigational information from supplementary land-based equipment. An example of this supplementary equipment is a radar beacon which consists of a transmitter that radiates a coded pulse when properly interrogated by an airborne system. This coded pulse appearing on the radar indicator enables range and bearing to be determined to the known location of the beacon. Such a system has a decided advantage when navigating over water where recognizable targets on a radar map are scarce. Furthermore, it aids in extending the operating range of the equipment beyond the target-response indication because of the higher power signals from the beacon. Since the high frequencies involved propagate only in straight lines, the range generally is limited to line of sight conditions.

## Future Developments

The elevation scope pictures illustrate the performance that is obtainable now with ground radar equipment, and in time, equivalent resolution and satisfactory ranges will be achieved with light-weight air-borne systems. However, there are many engineering problems, both electrical and mechanical, to be overcome before an ideal design is evolved that meets the strict limitations imposed upon air-borne apparatus. Not the least of these is the problem of presenting the radar information in a manner that requires little effort on the part of the observer for quick interpretation. Azimuth and elevation data should be combined to provide the pilot with continuous infor-

**Figure 17. Radar map of Greater New York**



mation on all obstacles within the danger area.

The photograph in Figure 17 illustrates the definition obtainable when using a very narrow beam system. The individual docks on the Manhattan water front, the bridges across the East River, and the railroad tracks in Jersey City are clearly visible. It may well be that eventually radar will approach the equivalent of visual or television presentation in a scope picture so that a similar view of New York City and adjacent areas will enable the pilot to perceive the height of objects with the same resolution that can be observed here for range and bearing. This goal may not be achieved for some time, if ever, but in the meantime, useful radar systems can be designed which will remove many of the hazards of modern air travel.

## References


1. Radar, a Report on Science at War (pamphlet), distributed by Office of War Information.

2. Aviation Communication System, D. W. Rentzel. Electrical Engineering, volume 64, November 1945, pages 387–91.

# Differential Leakage of a Fractional-Slot Winding

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MEMBER AIEE

IN a previous paper,[1] the differential (harmonic) leakage of an integral-slot winding and squirrel cage winding was treated. It was shown that a squirrel cage rotor reduces the harmonics and thus the differential leakage of the stator. The influence of the number of stator and rotor slots, as well as of the pitch factor of the stator winding on the damping of the stator harmonics, was discussed. Also, it was shown that skewing of the rotor reduces the damping of the stator harmonics and, therefore increases the differential leakage of the stator. The investigation was made under the following assumptions:

1. The saturation of the leakage paths is negligible.
2. The influence of slot-openings for all harmonics is the same as for the synchronous wave. That is, all harmonic fluxes are reduced by the slot-openings in the ratio of one to $K_c$, where $K_c$ is the total Carter factor.
3. The magnetomotive force curve has a stepped shape.

The saturation of the leakage paths will be neglected in this paper also. The influence of slot-openings on the individual harmonics and the influence of the shape of the magnetomotive force curve on the differential leakage are treated in appendixes I and II. It follows from these appendixes that the assumptions made with respect to the slot-openings and the shape of the magnetomotive force curve are not entirely correct, but they are justified by the simplification of calculation of the differential leakage to which they lead.

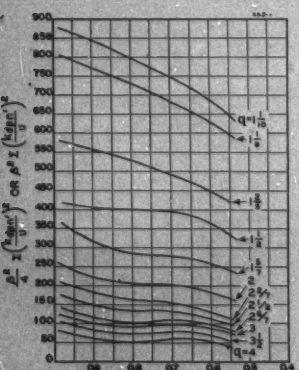


Figure 1. $\frac{\beta^2}{4}\sum_{\nu=\frac{\beta}{2}}^{\nu=\beta}\left(\frac{k_{d\rho\nu}}{\nu}\right)^2$ and $\beta^2\sum_{\nu=\beta}^{\nu=\beta}\left(\frac{k_{d\rho\nu}}{\nu}\right)^2$ for fractional-slot 3-phase windings

## Actual Harmonics of Fractional-Slot 3-Phase Winding: Their Distribution Factors and Pitch Factors

If the number of slots per pole per phase of the fractional-slot winding is written

$$q=\frac{N}{\beta} \tag{1}$$

where $N$ and $\beta$ have no common divisor, the actual harmonics of a 3-phase winding are (for symbols see Nomenclature):

$$\nu'=\frac{2p}{\beta}\nu \qquad \nu=1, 2, 4, 5, 7 \ldots \tag{2}$$

when $\beta$ is an even number, and

$$\nu'=\frac{p}{\beta}\nu \qquad \nu=1, 5, 7, 11, 13 \ldots \tag{3}$$

when $\beta$ is an odd number.

For the synchronous wave, $\nu_s = \beta/2$ when $\beta$ is an even number, or $\nu_s = \beta$ when $\beta$ is an odd number. The number of subharmonics is equal to $(\beta-2)/2$ when $\beta$ is an even number or to $(\beta-1)/2$ when $\beta$ is an odd number (including those which are a multiple of three and usually do not exist in a 3-phase machine).

The absolute value of the distribution factor of the $\nu'$-th harmonic is

$$k_{d\nu'}=\frac{0.5}{N\sin\alpha_{\nu'}/2} \tag{4}$$

If $P$ is the smallest integer which makes $d$ an integer in the equation,

$$d=\frac{3NP+1}{\beta} \tag{5}$$

then it is true that when $\beta$ is an even number

$$\alpha_{\nu'}=2d\alpha_{\nu P}+180 \tag{6}$$

and when $\beta$ is an odd number

$$\alpha_{\nu'}=d\alpha_{\nu P}$$

if $P$ is an even number and

$$\alpha_{\nu'}=d\alpha_{\nu P}+180 \tag{7}$$

if $P$ is an odd number where

$$\alpha_\nu=\frac{180}{3N} \tag{8}$$

The pitch factor of the $\nu'$-th harmonic is

$$k_{p\nu'}=\sin\left(\frac{W}{\tau}\frac{180}{\beta}\nu\right) \tag{9a}$$

when $\beta$ is an even number and

$$k_{p\nu'}=\sin\left(\frac{W}{\tau}\frac{180}{2\beta}\nu\right) \tag{9b}$$

when $\beta$ is an odd number.

## Harmonic Leakage Reactance of 3-Phase Winding

First the case will be considered where there is no damping, that is, the stator winding of a wound rotor induction motor or the stator winding of a salient pole synchronous machine without a damper winding.

The amplitude of the magnetomotive force of the wave with the length $2\beta\tau$ is

$$F_\beta=\frac{\sqrt{2}}{\pi}mNn_sk_{d\beta}I \tag{10}$$

and therefore the amplitude of the fundamental wave with the length $2p\tau$ is

$$F_f=\frac{\sqrt{2}}{\pi}mNn_sk_{d1}I\times\frac{\beta}{p} \tag{11}$$

The amplitude of the $\nu'$-th harmonic of the magnetomotive force is thus

$$F_{\nu'}=\frac{F_f}{\nu'}\frac{k_{d\nu'}}{k_{d1}}=\frac{\sqrt{2}}{\pi}mNn_s\frac{\beta}{p}\frac{k_{d\nu'}}{\nu'}I \tag{12}$$

If the assumption is made that all harmonics are reduced by the slot-openings in the ratio of one to $K_c$, then the amplitude of the $\nu'$-th field harmonic is

$$B_{\nu'}=\frac{3.19}{gK_cK_s}F_{\nu'} \tag{13}$$

and the flux produced by the $\nu'$-th field harmonic is

$$\Phi_{\nu'}=\frac{2}{\pi}\tau_{\nu'}l_iB_{\nu'} \tag{14}$$

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The author is grateful to B. Limes for assistance in calculating the data contained in Table I.

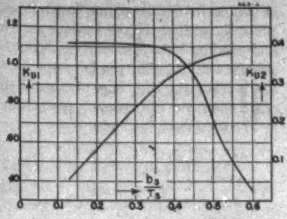



Figure 2. Factors $K_{01}$ and $K_{02}$ as functions of ratio between slot opening and slot pitch

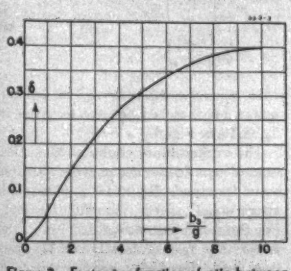



Figure 3. Factor $\delta$ as function of ratio between slot opening and air gap

The flux interlinkage caused by the flux $\Phi_{\nu'}$ is

$$\Psi_{\nu'}=\Phi_{\nu'}N_{ph}k_{dp\nu'} \tag{15}$$

Hence, the harmonic leakage reactance

$$x_h=2\pi f_1\frac{1}{\sqrt{2}I}\sum\Psi_{\nu'}\times10^{-8}\text{ ohms/phase}$$

$$x_h=\frac{4}{\pi^3}mf_1N_{ph}^2\frac{\tau l_i}{pg\overline{K}_c\overline{K}_s}10^{-7}\times\left[\frac{p}{\tau}\sum\left(\frac{\tau_{\nu'}}{\nu'}k^2_{dp\nu'}\right)\right]\text{ ohms/phase} \tag{16}$$

where

$$\tau_{\nu'}=\frac{p\tau}{\nu'}$$

Therefore, corresponding to equations 2 and 3,

$$\frac{p}{\tau}\sum\left(\frac{\tau_{\nu'}}{\nu'}k^2_{dp\nu'}\right)=\frac{\beta^2}{4}\sum_{\nu=\frac{\beta}{2}}\left(\frac{k_{dp\nu'}}{\nu}\right)^2$$
$$\nu=1,\ 2,\ 4,\ 5,\ 7\ \ldots \tag{17}$$

when $\beta$ is an even number and

$$\frac{p}{\tau}\sum\left(\frac{\tau_{\nu'}}{\nu'}k^2_{dp\nu'}\right)=\beta^2\sum_{\nu=\beta}\left(\frac{k_{dp\nu'}}{\nu}\right)^2$$
$$\nu=1,\ 5,\ 7,\ 11\ \ldots \tag{18}$$

when $\beta$ is an odd number.

The evaluation of the sums of equation 17 and equation 18 is not as simple as for an integral-slot winding. The reactance equation based upon the magnetic energy in the gap and used for the calculation of the harmonic leakage of the integral-slot winding also can be applied here, but the Goerges diagram of the magnetomotive forces of a fractional-slot winding becomes complicated, and the derivation of general formulas becomes tedious.

For this reason the direct summation of the terms $(k_{dp\nu'}/\nu)^2$ has been used in order to determine the sum of equations 17 and 18. As for the integral-slot windings, only a part of the harmonics of order lower than the slot harmonics of first order, and all slot harmonics, have to be taken into account.

The slot harmonics are:

$$\nu'_{sl}=\mp kQ+p \tag{19}$$

Thus

$$\nu_{sl}=\frac{\beta}{2}(\mp6kq+1) \tag{20}$$

when $\beta$ is an even number

$$\nu_{sl}=\beta(\mp6kq+1) \tag{21}$$

when $\beta$ is an odd number.

When $k>2$, the term $+1$ in the parentheses of equations 20 and 21 can be neglected. Then

$$\sum_{\nu=\nu_{sl}}\left(\frac{k_{dp\nu'}}{\nu}\right)^2=\frac{4}{\beta^2}k^2_{dp(\nu'=p)}\left[\frac{1}{(-6q+1)^2}+\frac{1}{(6q+1)^2}+\frac{1}{(-12q+1)^2}+\frac{1}{(12q+1)^2}+\frac{0.786}{(6q)^2}\right] \tag{22}$$

when $\beta$ is an even number and

$$\sum_{\nu=\nu_{sl}}\left(\frac{k_{dp\nu'}}{\nu}\right)^2=\frac{1}{\beta^2}k^2_{dp(\nu'=p)}\times\left[\frac{1}{(-6q+1)^2}+\frac{1}{(6q+1)^2}+\frac{1}{(-12q+1)^2}+\frac{1}{(12q+1)^2}+\frac{0.786}{(6q)^2}\right] \tag{23}$$

when $\beta$ is an odd number. Here is

$$k_{d(\nu'=p)}=\frac{\sin 30^\circ}{N\sin\frac{30^\circ}{N}} \tag{24}$$

and

$$k_{p(\nu'=p)}=\sin\frac{Z}{mq}\frac{\pi}{2}=\sin\frac{Z}{q}30^\circ \tag{25}$$

$Z$ is the coil width in slot pitches.

For the harmonics of lower order than the slot harmonics of first order, formulas 4 to 7 and also Calvert's Tables[2] have been used.

The results for the more frequently used numbers of slots per pole per phase are given in Table I. The third column does not include the subharmonics; however, the fourth column does.

It has been shown that the harmonics of lower order are damped by a squirrel cage more than the harmonics of higher order. This is especially true of the subharmonics; a squirrel cage winding in the induction motor or a damper winding in the synchronous machine damps out these harmonics practically entirely. Because of the high speed of the subharmonics, they are damped considerably by parasitic currents even when there is no squirrel cage or damper winding in the rotor. For the calculation of the harmonic leakage reactance, the subharmonics therefore can be omitted. This is also in agreement with the tests.

Figure 1 gives the sums of equations 17 and 18 without the subharmonics as function of the throw $W/\tau$. The values for $q=2$, 3, and 4 are taken from Figure 1 of reference 1. It can be seen that the curves for fractional-slot windings have the same characteristics as those for integral-slot windings. The ratio between the sums for the same value of $W/\tau$ approximately is equal to the inverse ratio of the square of $q$, and so Figure 1 of reference 1 can be used in order to determine the sum for fractional-slot windings with $q>3^1/_2$.

## Damping of Harmonics by Squirrel Cage Winding

The case of an induction motor with squirrel cage rotor or of a salient pole synchronous machine with damper winding will be considered now. Here the rotor harmonics which correspond to $K_s=0$ (see reference 1) damp the corresponding stator harmonics, thus reducing the leakage reactance. It has been shown there that the damping factor of the $\nu'$-th harmonic is

$$D_{\nu'}=1-\frac{js_{\nu'}X_{m\nu'}}{r_{2\nu'}+js_{\nu'}X_{m\nu'}(1+\tau_{2\nu'})} \tag{26}$$

or

$$D_{\nu'}=1-\underline{C}_{\nu'}/\underline{\theta} \tag{27}$$

where

$$C_{\nu'}=\frac{\sqrt{[(s_{\nu'}X_{m\nu'})^2(1+\tau_{2\nu'})]^2+(s_{\nu'}X_{m\nu'}r_{2\nu'})^2}}{r_{2\nu'}{}^2+[s_{\nu'}X_{m\nu'}(1+\tau_{2\nu'})]^2} \tag{28}$$

and

$$\tan\theta=\frac{r_{2\nu'}}{s_{\nu'}X_{m\nu'}(1+\tau_{2\nu'})} \tag{29}$$

The absolute value of $D_{\nu'}$ is

$$D_{\nu'}=\sqrt{(1-C_{\nu'}\cos\theta)^2+(C_{\nu'}\sin\theta)^2} \tag{30}$$

**Table I**

| $\nu$ | $\beta$ \| + | $\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2_{\nu\neq\beta}$ Without Subharmonics | $\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2_{\nu\neq\beta}$ Including Subharmonics | $\nu$ | $\beta$ \| + | $\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2_{\nu\neq\beta}$ Without Subharmonics | $\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2_{\nu\neq\beta}$ Including Subharmonics |
|---|---|---|---|---|---|---|---|
| 1 1/2 | 0.890 | 0.0403 | 0.0436 | 1 3/4 | 0.954 | 0.0570 | 0.0680 |
| | 0.667 | 0.0397 | 0.0392 | | 0.714 | 0.0495 | 0.0539 |
| 2 1/2 | 0.933 | 0.0153 | 0.0153 | 1 1/4 | 0.926 | 0.0297 | 0.0474 |
| | 0.800 | 0.0139 | 0.0139 | | 0.742 | 0.0256 | 0.0372 |
| 1 3/4 | 0.953 | 0.0314 | 0.0488 | 2 1/4 | 0.910 | 0.0188 | 0.0308 |
| | 0.750 | 0.0264 | 0.0383 | | 0.758 | 0.0167 | 0.0251 |
| 2 1/4 | 0.890 | 0.0175 | 0.0283 | 1 3/7 | 0.972 | 0.0354 | 0.0522 |
| | 0.740 | 0.0158 | 0.0237 | | 0.778 | 0.0281 | 0.0402 |
| 2 3/4 | 0.969 | 0.0139 | 0.0212 | 2 3/7 | 0.874 | 0.0175 | 0.0272 |
| | 0.850 | 0.0114 | 0.0174 | | 0.730 | 0.0164 | 0.0237 |
| 1 7/8 | 0.890 | 0.0263 | 0.0447 | 2 5/7 | 0.933 | 0.0119 | 0.0201 |
| | 0.712 | 0.0246 | 0.0366 | | 0.817 | 0.0105 | 0.0172 |
| 2 5/8 | 0.983 | 0.0207 | 0.0253 | 1 7/11 | 0.815 | 0.0299 | 0.0369 |
| | 0.842 | 0.0184 | 0.0221 | | 0.612 | 0.0240 | 0.0283 |
| 2 7/8 | 0.938 | 0.0124 | 0.0208 | 2 1/11 | 0.958 | 0.0255 | 0.0399 |
| | 0.812 | 0.0120 | 0.0187 | | 0.798 | 0.0320 | 0.0347 |
| | | | | 2 7/11 | 0.885 | 0.0155 | 0.0186 |
| | | | | | 0.760 | 0.0138 | 0.0152 |
| | | | | 1 11/13 | 0.903 | 0.0271 | 0.0452 |
| | | | | | 0.723 | 0.0245 | 0.0371 |
| | | | | 2 1/13 | 0.867 | 0.0173 | 0.0260 |
| | | | | | 0.733 | 0.0156 | 0.0223 |
| | | | | 2 12/13 | 0.964 | 0.0135 | 0.0216 |
| | | | | | 0.842 | 0.0112 | 0.0177 |

A comparison between the last two columns shows that the slot leakage and the end-winding leakage cannot be neglected despite the fact that the harmonic leakage is relatively large here because of the small number of slots per pole of the rotor.

The total damping factor is

$$D_t=\frac{\frac{\beta^2}{4}\sum\left(\frac{k_{dpn'}}{\nu}\right)^2 D_{n'}}{\frac{\beta^2}{4}\sum\left(\frac{k_{dpn'}}{\nu}\right)^2} \qquad \nu\neq\frac{\beta}{2} \tag{33}$$

when $\beta$ is an even number and

$$D_t=\frac{\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2 D_{n'}}{\beta^2\sum\left(\frac{k_{dpn'}}{\nu}\right)^2} \qquad \nu\neq\beta \tag{34}$$

when $\beta$ is an odd number. The denominators of these equations are given in Table I and Figure 1.

The evaluation of equation 34 for the example considered above gives the same value for standstill and for running with synchronous speed, namely, $D_t=0.92$. For the slot harmonics of first order, the factors $D_{n'}$, from Tables II and III have been used. For higher slot harmonics, it has been assumed that $D_{n'}$ equals one and equations 22 and 23 have been applied.

The motor in question has a throw equal to 0.788. The factor $D_t$ has been determined for the throw 0.972 also and has been found to be practically the same as for the throw 0.788. This is in accordance with the results obtained for the integral-slot windings with $q=2$. Also, there the chording has little influence on the damping.

## Influence of Slot Openings and Shape of Magnetomotive Force Curve on Harmonic Leakage

The previous considerations are based upon the assumption that the slot-openings reduce all field harmonics in the ratio of one to $K_c$. It is shown in Appen-

It has been shown in reference 1 that there will not be a sensible error when equation 30 is used instead of equation 26.

When $r_{2n'}$ can be neglected,

$$D_{n'}=1-\frac{1}{1+\tau_{2n'}} \tag{31}$$

and when, besides $r_{2n'}$, the slot leakage and the end-winding leakage also can be neglected comparatively with harmonic leakage,

$$D_{n'}=1-(\xi_{2n'}\eta_{2n'})^2 \tag{32}$$

where $\xi_{2n'}$ is the coupling factor of the rotor with respect to the $n'$-th harmonic and $\eta_{2n'}$ is the skew factor.

As an example, a 350-horsepower 60-cycle, 3-phase synchronous motor with 28 poles will be considered. $Q_1=144$, $q_1=1^5/_7$, $Q_2=5\times28=140$, $W/\tau=0.788$. The damper winding consists of five round bars per pole, three of them of copper, two of bronze with the resistivity two. The poles are not skewed. The motor will be considered at standstill ($s=s_{n'}=1$) and running with normal speed ($s=0$, $s_{n'}=$ variable).

Table II gives the values of the rotor constants as well as of $C_{n'}$, $\tan\theta$, and $D_{n'}$ for standstill ($s_{n'}=1$). Table II gives the same values for synchronous speed ($s_{n'}$ variable). The skin-effect has been neglected and thus both tables have the same values for $r_{2n'}$ and $\tau_{(z+c)n'}$.

The examination of the tables shows that they have the same character as those for integral slot windings[1] and that the influence of the resistance is small.

**Table II. Standstill**

| $\nu$ | $n'$ | $\vartheta_{n'}$ | $X_{mn'}\times10^{-4}$ | $r_{2n'}$ | $\tau_{(z+c)n'}$ | $\tau_{hn'}$ | $\tau_{2n'}$ | $\tan\theta$ | $C_{n'}$ | $D_{n'}$ | $D_{n'}$ for $r_{2n'}=0$ | $D_{n'}$ for $r_{2n'}=0$ and $\tau_{(z+c)n'}=0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | + 2 | 1 | 1,304 | 9.01 | 0.0082 | 0.005 | 0.0132 | 0.0068 | 0.988 | 0.0138 | 0.013 | 0.005 |
| 5 | − 10 | 1 | 52. | 1.66 | 0.0715 | 0.02 | 0.0915 | 0.0293 | 0.920 | 0.090 | 0.0837 | 0.0198 |
| 11 | − 22 | 1 | 10.72 | 1.42 | 0.332 | 0.047 | 0.379 | 0.0967 | 0.733 | 0.288 | 0.275 | 0.045 |
| 13 | + 26 | 1 | 7.68 | 1.41 | 0.46 | 0.064 | 0.524 | 0.120 | 0.652 | 0.361 | 0.344 | 0.060 |
| 17 | − 34 | 1 | 4.49 | 1.39 | 0.785 | 0.111 | 0.896 | 0.164 | 0.533 | 0.49 | 0.472 | 0.10 |
| 19 | + 38 | 1 | 3.6 | 1.39 | 0.975 | 0.156 | 1.131 | 0.181 | 0.468 | 0.556 | 0.531 | 0.135 |
| 23 | − 46 | 1 | 2.46 | 1.38 | 1.43 | 0.196 | 1.626 | 0.214 | 0.377 | 0.635 | 0.619 | 0.164 |
| 25 | + 50 | 1 | 2.08 | 1.38 | 1.69 | 0.235 | 1.925 | 0.226 | 0.336 | 0.675 | 0.658 | 0.191 |
| 35 | − 70 | 1 | 1.06 | 1.375 | 3.3 | 0.535 | 3.83 | 0.260 | 0.200 | 0.81 | 0.794 | 0.359 |
| 49 | + 98 | 1 | 0.541 | 1.37 | 6.48 | 1.47 | 7.95 | 0.283 | 0.100 | 0.895 | 0.889 | 0.595 |
| 65 | −130 | 1 | 0.307 | 1.375 | 11.42 | 4.55 | 15.97 | 0.265 | 0.057 | 0.945 | 0.941 | 0.82 |
| 73 | +150 | 1 | 0.208 | 1.38 | 16.92 | 17.86 | 34.78 | 0.187 | 0.0272 | 0.972 | 0.971 | 0.947 |

dix I that this assumption is not true of the slot-harmonics. Depending upon the number of slots per pole and the coil pitch, one of the slot-harmonics of first or second order may be increased by the slot-openings while the other slot-harmonic of the same pair is decreased. It is even possible that both slot-harmonics of the first or second order are increased by the slot-openings. Further, the influence of the slot-openings on the slot-harmonics of higher order than two is negligible. This shows that the division of all harmonics by the Carter factor (equation 13) leads to too small a value of the harmonic leakage, the error being larger the larger the ratio of slot-opening to slot pitch and of slot-opening to air gap, that is, the error being larger for open slots than for semiopen slots.

On the other hand, it is shown in Appendix II that the calculation with the stepped magnetomotive force curve, based upon the assumption that the ampere conductors of each slot are concentrated in the middle of the slot, leads to too large amplitudes of the slot-harmonics and, therefore, to a too large value of the harmonic leakage, the error being again larger the larger the slot-opening.

The error caused by the division of all harmonics by the Carter factor and the error caused by the assumption of the stepped shape for the magnetomotive force curve are thus of opposite sense, one decreasing the slot harmonics and the harmonic leakage, the other increasing them.

## Conclusion

Experience shows that Figure 1 (as well as Figure 1 of reference 1) yields good practical results for the differential (harmonic) leakage, that is, results which agree with tests. Since these figures do not take into account the damping of the harmonics by the rotor and are based upon the assumptions that the slot-openings reduce equally all harmonics and that the magnetomotive force curve has a stepped shape, their good agreement with tests means that the error caused by the division of all harmonics by the Carter factor is approximately equal and opposite to the errors caused by the neglect of damping and the assumption of the stepped magnetomotive force curve.

Since the differential (harmonic) leakage constitutes only a part of the total leakage, the use of a simple, although not entirely exact method of calculation of this leakage, is justified.

## Appendix I. Influence of the Slot Openings on the Differential Leakage

The stator of an induction motor will be considered. The results obtained apply also to the rotor.

The $n'$-th harmonic of the magnetomotive force curve is

$$f_{n'} = F_{n'} \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right) \tag{35}$$

$$F_{n'} = \frac{\sqrt{2}}{\pi} m_1 N_1 \frac{k_{dpn'}}{n'} I_1 \tag{36}$$

The $n'$-th field harmonic has been derived from this (see equation 13) by multiplying with

$$\frac{3.19}{gK_{c1}K_{c2}K_s}$$

where the Carter factors $K_{c1}$ and $K_{c2}$ have to take care of the influence of the slot-openings of stator and rotor. This yields for $n'$-th field harmonic

$$b_{n'} = \frac{3.19}{gK_{c1}K_{c2}K_s} F_{n'} \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right) \tag{37}$$

In order to determine more accurately the influence of the slot-openings, the gap permeance will be introduced[4] in accordance with the assumption that the fundamental has two poles, as

$$\left(\frac{1}{g}\right)_{eff} = \frac{1}{g}\left[1 + \epsilon_1 \cos Q_1\frac{\pi}{p\tau}x + \epsilon_2 \times \cos 2Q_1\frac{\pi}{p\tau}x + \dots\right] \tag{38}$$

The $n'$-th field harmonic becomes

$$b_{n'} = \frac{3.19}{gK_s} F_{n'} \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right) \times \left[1 + \epsilon_1 \cos Q_1\frac{\pi}{p\tau}x + \epsilon_2 \cos 2Q_1\frac{\pi}{p\tau}x + \dots\right] \tag{39}$$

With the abbreviation

$$\frac{3.19}{gK_s} F_{n'} = A_{n'} \tag{40}$$

there is

$$b_{n'} = A_{n'} \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right) + A_{n'} \sum_{c=1,2,3\dots} \epsilon_c \times \cos\left(cQ_1\frac{\pi}{p\tau}x\right) \times \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right)$$

or

$$b_{n'} = A_{n'} \sin\left(\omega t - n'\frac{\pi}{p\tau}x\right) + A_{n'} \sum_{c=1,2,3\dots} \frac{\epsilon_c}{2} \times \left\{\sin\left[\omega t + (cQ_1 - n')\frac{\pi}{p\tau}x\right] + \sin\left[\omega t - (cQ_1 + n')\frac{\pi}{p\tau}x\right]\right\} \tag{41}$$

Thus, because of the slot-openings of the stator, the $n'$-th stator harmonic produces a series of pairs of traveling waves. One wave of each pair travels in the direction of rotation, the other in opposite direction. Their respective velocities with regard to the stator are

$$\frac{p}{cQ_1 + n'}\frac{\tau}{\pi}\omega \text{ and } \frac{p}{cQ_1 - n'}\frac{\tau}{\pi}\omega \qquad c = 1, 2, 3\dots \tag{42}$$

These slot-opening waves may influence considerably those field harmonics with respect to which they are at standstill. Their influence on all other harmonics will be relatively small and can be taken care of by introducing the Carter factor, that is, by introducing in the denominator of equation 40 the factor $K_{c1}$.

The latter statement applies also to the influence of the rotor slot-openings on the stator harmonics, since the waves produced by them move with respect to the stator harmonics. Therefore, considering the stator

**Table III. Synchronous Speed**

| $p$ | $n'$ | $\epsilon_{n'}$ | $X_{mn'}$ | $r_{2n'}$ | $r_{1+\sigma 1n'}$ | $r_{1n'}$ | $r_{2n'}$ | $\tan\theta$ | $C_{n'}$ | $D_{n'}$ | $D_{n'}$ for $r_{2n'}=0$ | $D_{n'}$ for $r_{2n'}=0$ and $x_{1+\sigma 1n'}=0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | + 2 | + 0.857 | $1.304\times10^{-4}$ | $9.01\times10^{-4}$ | 0.0082 | 0.005 | 0.0132 | 0.0079 | 0.986 | 0.016 | 0.0128 | 0.005 |
| 5 | − 10 | + 1.715 | 52. | 1.66 | 0.0715 | 0.02 | 0.0915 | 0.0171 | 0.915 | 0.085 | 0.0837 | 0.0196 |
| 11 | − 22 | + 2.57 | 10.72 | 1.43 | 0.332 | 0.047 | 0.379 | 0.376 | 0.727 | 0.276 | 0.275 | 0.045 |
| 13 | + 26 | − 0.86 | 7.68 | 1.41 | 0.46 | 0.064 | 0.524 | 0.14 | 0.654 | 0.354 | 0.344 | 0.060 |
| 17 | − 34 | + 3.43 | 4.49 | 1.39 | 0.785 | 0.111 | 0.896 | 0.0467 | 0.530 | 0.475 | 0.472 | 0.10 |
| 19 | + 38 | − 1.72 | 3.6 | 1.39 | 0.975 | 0.156 | 1.131 | 0.105 | 0.470 | 0.535 | 0.531 | 0.135 |
| 23 | − 46 | + 4.29 | 2.46 | 1.38 | 1.43 | 0.196 | 1.626 | 0.0496 | 0.377 | 0.624 | 0.619 | 0.164 |
| 25 | + 50 | − 2.57 | 2.08 | 1.38 | 1.69 | 0.235 | 1.925 | 0.085 | 0.345 | 0.658 | 0.653 | 0.191 |
| 35 | − 70 | + 6.0 | 1.06 | 1.375 | 3.3 | 0.635 | 3.83 | 0.0448 | 0.207 | 0.794 | 0.794 | 0.359 |
| 49 | + 98 | − 6.0 | 0.541 | 1.37 | 6.48 | 1.47 | 7.95 | 0.047 | 0.111 | 0.889 | 0.889 | 0.595 |
| 65 | −130 | +10.3 | 0.307 | 1.375 | 11.42 | 4.55 | 15.97 | 0.0257 | 0.059 | 0.941 | 0.941 | 0.82 |
| 75 | +150 | −10.3 | 0.208 | 1.38 | 16.92 | 17.86 | 34.78 | 0.0182 | 0.028 | 0.971 | 0.971 | 0.947 |

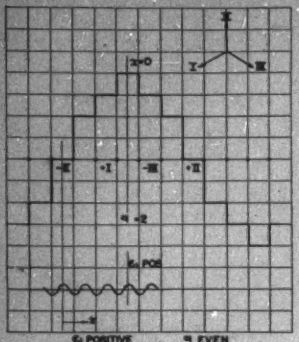



Figure 4. Determination of the signs of $\epsilon_1$ and $\epsilon_2$ for $q$ = even number

harmonics, the factor $K_{p1}$ has to be introduced in equation 40.

Now the stator field harmonics have to be determined, the velocities of which are given by equation 42. These stator field harmonics will be increased or reduced considerably by the slot-opening waves.

The $n'$-th stator harmonic has with respect to the stator the speed

$$v_{n'} = \frac{p}{n'\pi}\omega \tag{43}$$

Since the order of the stator slot-harmonics is given by the equation

$$n'_{sl} = \mp kQ_1 + p \tag{44}$$

it follows that the slot-opening waves produced by the synchronous wave ($n' = p$) are at standstill with respect to the slot-harmonics and these are the only waves which are at standstill with respect to each other. It follows further from equations 42 and 44 that the slot-opening wave of the order $c = 1$ is at standstill with respect to the slot-harmonic of first order ($k = 1$), that the slot-opening wave of the order $c = 2$ is at standstill with respect to the slot-harmonic of second order ($k = 2$), and so on.

Usually only the slot-opening waves of the orders $c = 1$ and $c = 2$ have to be taken into account. From equation 41

$$b'_{s0} = A_{(n'=p)}\frac{\epsilon_2}{2}\sin\left[\omega t - (cQ_1 + p)\frac{\pi}{pr}x - \psi\right]\frac{I_m}{I_1} \tag{45}$$

and

$$b''_{s0} = A_{(n'=p)}\frac{\epsilon_2}{2}\sin\left[\omega t + (cQ_1 - p)\frac{\pi}{pr}x + \psi\right]\frac{I_m}{I_1} \tag{46}$$

where $I_m$ is the magnetizing current. $A_{(n'=p)}$ is proportional to the primary current $I_1$. The factor $I_m/I_1$ takes into account the fact that the amplitude of the slot-opening waves is proportional to the resultant synchronous wave, that is, to the synchronous wave produced by the primary and secondary magnetomotive force together ($I_m$). The angle has to be introduced because $I_m$ is not in phase with $I_1$.

The slot harmonics are

$$b'_{sl} = A_{(n'=cQ_1+p)}\sin\left[\omega t - (cQ_1 + p)\frac{\pi}{pr}x\right] \tag{47}$$

$$b''_{sl} = A_{(n'=-cQ_1+p)}\sin\left[\omega t + (cQ_1 - p)\frac{\pi}{pr}x\right] \tag{48}$$

The ratio between the amplitudes of the two waves which travel in the direction of rotation is

$$r' = \frac{A_{(n'=p)}}{A_{(n'=cQ_1+p)}}\frac{I_m}{I_1}\frac{\epsilon_2}{2} = -\left[\frac{k_{d(n'=p)}}{k_{d(n'=cQ_1+p)}}\right]\left[\frac{k_{p(n'=p)}}{k_{p(n'=cQ_1+p)}}\right]\times \frac{cQ_1+p}{p}\frac{I_m}{I_1}\frac{\epsilon_2}{2} \tag{49}$$

and the ratio between the amplitudes of the two waves which travel opposite to the direction of rotation is

$$r'' = \frac{A_{(n'=p)}}{A_{(n'=-cQ_1+p)}}\frac{I_m}{I_1}\frac{\epsilon_2}{2} = -\left[\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}}\right]\left[\frac{k_{p(n'=p)}}{k_{p(n'=-cQ_1+p)}}\right]\times \frac{cQ_1-p}{p}\frac{I_m}{I_1}\frac{\epsilon_2}{2} \tag{50}$$

The ratio $I_m/I_1$ as well as the angle $\psi$ depend on the speed of the machine. For the induction motor it is approximately

$$\left.\begin{aligned}\frac{I_m}{I_1} &= 0.08\text{ to }0.2\\ \psi &= 15^\circ\text{ to }25^\circ\end{aligned}\right\}\quad\text{at standstill} \tag{51}$$

$$\left.\begin{aligned}\frac{I_m}{I_1} &= 0.22\text{ to }0.6\\ \psi &= 78^\circ\text{ to }55^\circ\end{aligned}\right\}\quad\text{at high speed} \tag{52}$$

The first value refers to machines with a low number of poles, the second to machines with a high number of poles. For the synchronous motor, $I_m/I_1 \approx 0.35$ at standstill and $I_m/I_1 \approx 0.8$ to 1.1 at high speed; $\psi$ is for both cases approximately 25 degrees.

Further, for integral-slot windings

$$\left.\begin{aligned}\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}} &= -1 (c=1)\\ &= +1 (c=2)\end{aligned}\right\}\quad\text{when } q \text{ is even}$$

$$\left.\begin{aligned}\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}} &= +1 (c=1)\\ &= +1 (c=2)\end{aligned}\right\}\quad\text{when } q \text{ is odd} \tag{53}$$

and for fractional-slot windings[3]

$$\left.\begin{aligned}\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}} &= +1 (c=1)\\ &= -1 (c=2)\end{aligned}\right\}\quad\text{when } P \text{ is even}$$

$$\left.\begin{aligned}\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}} &= +1 (c=1)\\ &= +1 (c=2)\end{aligned}\right\}\quad\text{when } P \text{ is odd and } \beta \text{ is even}$$

$$\left.\begin{aligned}\frac{k_{d(n'=p)}}{k_{d(n'=-cQ_1+p)}} &= -1 (c=1)\\ &= +1 (c=2)\end{aligned}\right\}\quad\text{when } P \text{ is odd and } \beta \text{ is odd} \tag{54}$$

For the ratio of the pitch factors,

$$\frac{k_{p(n'=p)}}{k_{p(n'=-cQ_1+p)}} = +1 \text{ or } -1 \tag{55}$$

that is, when one slot-harmonic has the plus sign, the other slot-harmonic of the same pair has the minus sign.

The magnitude of $\epsilon_1$ depends upon the ratio between slot-opening and slot pitch and upon the ratio between slot-opening and gap. There is[5]

$$\epsilon = K_\tau \delta K_c \tag{56}$$

The factor $K_\tau$ takes into account the ratio between slot-opening and slot pitch; its value for $c = 1$ and $c = 2$ is given in Figure 2. $\delta$ takes into account the ratio between slot-opening and air gap; its value is given in Figure 3. $K_c = K_{c1}K_{c2}$ is the Carter factor. For open slots, $\epsilon_1 = 0.5$ to $0.7$ and $\epsilon_2$ is negligible; for semi-open slots $\epsilon_1 = 0.05$ to $0.25$ and $\epsilon_2 = 0.05$ to $0.15$.

In order to find the sign of $\epsilon_1$ with respect to the synchronous wave, consider Figures 4 and 5, which relate to integral-slot windings with $q = 2$ and $q = 3$. It can be seen that $\epsilon_1$ is positive for even and negative for odd values of $q$, while $\epsilon_2$ is negative for even as well as odd values of $q$.

Because of the slot-opening waves produced by the synchronous wave ($n' = p$), one slot-harmonic of a pair may be decreased and the other increased, or both slot-harmonics of the pair may be decreased or increased. Whether the harmonic is decreased or increased depends upon the number of slots per pole and upon the coil pitch, that is, upon the sign of the pitch factor.

Equations 51 and 52 show further that the influence of the slot-openings depends upon the speed of the machine. The harmonic (differential) leakage is therefore not a constant; it changes with the speed of the machine.

As example the stator harmonics of an 800-horsepower 8-pole induction motor with open slots will be considered.

For this machine

$$\frac{b_1}{t} = \frac{0.415}{0.055} = 7.49$$

$$\frac{b_2}{\tau_2} = \frac{0.415}{0.789} = 0.527$$

From Figures 2 and 3,

$$K_{\tau 1} = 1.06 \qquad K_{\tau 2} = 0.14 \qquad \delta = 0.37$$

The Carter factor is equal to 1.46. Therefore,

$$\frac{\epsilon_1}{2} = 1.06 \times 0.37 \times 1.46 \times 0.5 = 0.286$$

Further,

$$\frac{I_m}{I_1} = 0.239 \text{ at full speed}$$

$$\frac{I_m}{I_1} = 0.06 \text{ at standstill}$$

For the machine under consideration,

$$q = 5 \qquad \frac{W}{\tau} = 0.733$$

Hence,

$$\frac{k_{d(n'-p)}}{k_{d(n'=-o_1+p)}}=+1$$

and

$$\frac{k_{p(n'-p)}}{k_{p(n'=o_1+p)}}=-1 \qquad \frac{k_{p(n'-p)}}{k_{p(n'=-o_1+p)}}=+1$$

It follows from equations 39 and 40 for the slot harmonics of first order,

$$r'=(+1)(-1)\frac{120+4}{4}\times 0.239\times(-0.286)=$$
$$+2.12 \text{ at full speed}$$

$$r''=(+1)(+1)\frac{120-4}{4}\times 0.239\times(-0.286)=$$
$$-1.98 \text{ at full speed}$$

$$r'=+2.12\frac{0.06}{0.239}=+0.532 \text{ at standstill}$$

$$r''=-1.98\frac{0.06}{0.239}=-0.497 \text{ at standstill}$$

From the two waves of first order produced by the slot-openings, one, which travels with the rotation, has a sign opposite to the corresponding slot-harmonic, while the other, which travels opposite to the direction of rotation, has the same sign as the corresponding slot-harmonic. At standstill, the slot-harmonic that has the same direction of rotation as the synchronous wave is reduced by approximately 50 per cent while the other slot-harmonic is increased by approximately the same amount. The influence of the slot-openings on the slot-harmonics of second order is small here because of the open slots. It should be noted that the influence of the slot-openings on the slot-harmonics of first order is much smaller than in the considered example when the slots are semi-closed. However, in this case the slot-harmonics of second order are more influenced than in the case of open slots.

In the calculation of the harmonic (differential) leakage (equation 13), the influence of the slot-openings has been taken care of by dividing the amplitudes of the harmonics by the Carter factor, that is, by calculating with an increased gap. It follows from the results obtained above that the division by the Carter factor is correct only for the harmonics of lower order but not for the slot-harmonics.

## Appendix II. Influence of the Shape of the Magnetomotive Force Curve

The foregoing considerations are based on the assumption that the magnetomotive force has the stepped shape, that is, that the magnetomotive force of a single coil is a rectangle and that the magnetomotive force changes in the center of each slot abruptly. This assumption is not correct. Flux maps indicate that it would be more correct to assume that, because of the slot-opening, the magnetomotive force of each single coil is not a rectangle but a trapezoid, as shown in Figure 6. This yields for the $n'$-th harmonic of an unchorded 3-phase integral-slot winding[4]

$$f_{n'}=\frac{3\sqrt{2}}{\pi}N_{ph}I\frac{k_{dn'}}{n'}\frac{\sin n'\alpha/2}{n'\alpha/2}\times$$
$$\sin\left(\omega t\mp n'\frac{\pi}{\rho\tau}x\right) \quad (57)$$

where

$$\alpha=\frac{b_s}{\rho\tau} \quad (58)$$

For the rectangular shape (equations 35 and 36)

$$f_{n'}=\frac{3\sqrt{2}}{\pi}N_{ph}I\frac{k_{dn'}}{n'}\sin\left(\omega t\mp n'\frac{\pi}{\rho\tau}x\right) \quad (59)$$

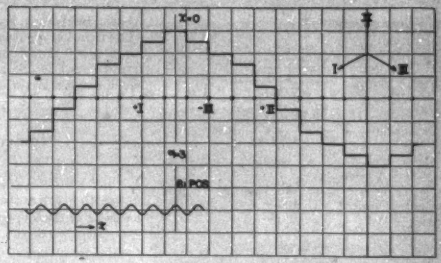
Thus, the assumption of a trapezoidal shape introduces the factor

$$k_b=\frac{\sin n'\alpha/2}{n'\alpha/2} \quad (60)$$

Since $\alpha$ is a small angle, this factor will not influence the harmonics of lower order, but it will reduce the slot harmonics considerably, especially those of higher order. The harmonic (differential) leakage reactance that is built up by the sum of the leakage reactances of all harmonics, therefore, will be reduced also. The reduction caused by the trapezoid shape of the magnetomotive force will be larger the smaller the number of slots per pole per phase $q$, since $n'\alpha$ increases with decreasing $q$.

Figure 5. Determination of signs of $\epsilon_1$ and $\epsilon_2$ for $q$ = odd number

$\epsilon_1$ negative
$\epsilon_2$ negative



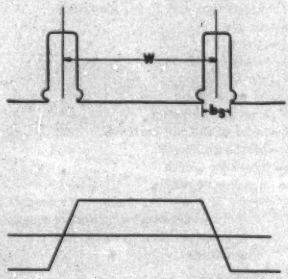




Figure 6. Shape of the magnetomotive force of a single coil in open slots

On the basis of equation 57, the harmonic leakage reactance of an unchorded 3-phase integral-slot winding becomes

$$x_h=\frac{4}{\pi^2}mN_{ph}^2pf_1l\times10^{-7}\sum\left(\frac{k_{dn'}}{n'}\right)^2\times$$
$$\frac{\sin n'\alpha/2}{p\alpha/2}\coth\left(n'\frac{\pi g}{p\tau}\right) \quad (61)$$

For the rectangular shape of the magnetomotive force

$$x_h=\frac{4}{\pi^2}m\frac{N_{ph}^2}{p}f_1l_i\frac{\tau}{gK_cK_s}10^{-7}\sum\left(\frac{k_{dn'}}{n'}\right)^2 \quad (62)$$

While the evaluation of the sum in equation 61 is very tedious, the sum in equation 62 can be expressed by a simple formula. For this reason the calculation with the step-shaped magnetomotive force is preferred.

In the specific case of equation 61, that is, for unchorded 3-phase integral-slot windings, the following approximate formula applies:

$$x_h=4.0\frac{N_{ph}^2}{p}f_1l10^{-7}\frac{\frac{\tau}{g'}+4q}{1{,}000}\left(0.6+\frac{b_s6.5-0.6g}{\tau_s\ q-1.2}\right) \quad (63)$$

$g'$ is eqnal to the gap, $g$, times the Carter factor of the opposite slot.

The results obtained from equations 62 and 63 will be compared for two machines with different numbers of slots per pole per phase.

1. Six-hundred-horsepower induction motor considered in Appendix I: For this machine

$m=3$ $N_{ph}=80$ $p=4$ $f_1=60$ $\tau=11.81$
$l=11$ $l_i=10$ $\tau_s=0.789$ $b_s=0.415$
$g=0.055$ $K_c=1.464$ $K_s=1.047$
$K_s=1.05$ $q=5$ $\sum\left(\frac{k_{dn}}{n}\right)^2=0.0059$

$\left(\text{for } \frac{W}{\tau}=1\right)$

It follows from equation 62

$$x_h=\frac{4}{\pi^2}3\frac{80^2}{4}60\times10\times$$
$$\frac{11.81}{0.055\times1.464\times1.047\times1.05}\times$$
$$0.0059\times10^{-7}=0.0873 \text{ ohm/phase}$$

and from equation 63

$$x_h = 4\frac{80^2}{4}60\times11\frac{11.81}{\frac{0.055\times1.047}{1,000}}+4\times5\times\left(0.6+\frac{0.374}{0.789}\frac{6.5-0.6\times5}{5-1.2}\right)10^{-7}$$

$$=0.098 \text{ ohm/phase}$$

2. Twelve-hundred-horsepower 26-pole induction motor with open slots: For this motor

$m=3 \quad N_{ph}=195 \quad p=13 \quad f_1=60 \quad \tau=8.12$
$l=24 \quad l_i=21 \quad \tau_s=0.901 \quad b_s=0.47 \quad g=0.065$
$K_{c1}=1.447 \quad K_{c2}=1.025 \quad K_s=1.05 \quad q=3$

$$\sum\left(\frac{k_{dn}}{n}\right)^2=0.0129\left(\text{for } \frac{W}{\tau}=1\right)$$

It follows from equation 62

$$x_h=\frac{4}{\pi^2}3\frac{150^2}{13}60\times21\times\frac{8.12}{0.065\times1.447\times1.025\times1.05}\times0.0129\times10^{-7}=0.275 \text{ ohm/phase}$$

and from equation 63

$$x_h=4\frac{150^2}{13}60\times24\frac{8.12}{\frac{0.065\times1.025}{1,000}}+4\times3\times\left(0.6+\frac{0.431}{0.901}\frac{6.5-0.6\times3}{3-1.2}\right)10^{-7}$$

$$=0.247 \text{ ohm/phase}$$

The values of the harmonic leakage obtained from equation 62, that is, on the basis of the stepped shape of the magnetomotive force curve, are about 10 to 15 per cent higher than those obtained from equation 63, that is, on the basis of the trapezoidal shape of the magnetomotive force curve. In the considered examples, $q$ is equal to three and five, respectively. The difference between the results yielded by equations 62 and 63 becomes larger for values of $q$ smaller than three; further, it is smaller for semi-open slots than for open slots; but in all cases the harmonic leakage obtained on the basis of the stepped shape of the magnetomotive force curve is larger than its real value.

## Nomenclature

$b_s$ = slot width at the gap
$b_t$ = tooth width at the gap
$c$ = order of the slot-opening wave
$D$ = damping factor
$f_1$ = line frequency
$f$ = magnetomotive force, instantaneous value
$F$ = magnetomotive force, amplitude
$g$ = air gap
$I$ = current
$k_d$ = distribution factor
$k_p$ = pitch factor
$K_c$ = Carter factor
$K_s$ = saturation factor
$k$ = order of the slot-harmonic
$l_i$ = ideal core length
$l$ = total core length
$m$ = number of phases
$n'$ = order of stator harmonics with respect to a fundamental whose wave length is equal to the circumference of the armature
$\left(n=\frac{n'}{p}\right)$ = order of the stator harmonic with respect to the synchronous wave
$n'_{sl}$ = order of the slot harmonics
$n_c$ = number of conductors in series per slot
$N$ = numerator of the fraction $q=N/\beta$, that is, number of slots per phase in $\beta$ poles
$N_{ph}$ or $N_1$ = number of turns per phase
$p$ = number of pole pairs
$P$ = smallest integer which makes $d$ in the equation $d=(3NP+1)/\beta$ an integer
$Q$ = total number of slots
$\left(q=\frac{N}{\beta}\right)$ = number of slots per phase per pole
$r_b$ = resistance of the rotor per bar
$s$ = slip of the rotor with respect to the synchronous wave
$s_{n'}$ = slip of the rotor with respect to the $n'$-th stator harmonic
$W$ = coil width (in units of the pole pitch)
$X_m$ = reactance due to the main flux
$x_h$ = differential (harmonic) leakage reactance per phase
$Z$ = coil width in slot pitches
$\beta$ = denominator of the fraction $q=N/\beta$
$\epsilon$ = amplitude of the slot-opening wave
$\eta$ = skew factor
$\xi$ = coupling factor of the squirrel cage rotor
$\tau$ = pole pitch of the synchronous wave
$\tau_{n'}$ = pole pitch of the $n'$-th harmonic
$\tau_s$ = slot pitch
$\tau_b$ = total leakage coefficient of the rotor
$\tau_{(s+e)}$ = slot and end-winding leakage coefficient of the rotor
$\tau_h$ = differential leakage coefficient of the rotor
$\omega=2\pi f_1$

## References


1. Differential Leakage With Respect to the Fundamental Wave and to the Harmonics, M. M. Liwschitz. AIEE Transactions, volume 63, 1944, October section, pages 1139–50. See also the bibliography to this paper containing 42 publications on the subject.

2. Distribution Factors and Pitch Factors of the Harmonics of a Fractional-Slot Winding, M. M. Liwschitz. AIEE Transactions, volume 62, 1943, October section, pages 664–6.

3. Amplitudes of Magnetomotive Force Harmonics for Fractional-Slot Windings of Three-Phase Machines, J. F. Calvert. *Iowa Engineering Experiment Station, Bulletin* 142, 1939.

4. The Theory of the Induction Motor With Squirrel Cage Rotor, L. Dreyfus. *Handlingar Number 34, Ingeniors Vetenskaps Akademiens* (Stockholm, Sweden), 1924.

5. Additional Losses in the Squirrel Cage Windings of Induction Motors and Synchronous Machines, M. M. Liwschitz, H. Raymund. *Scientific Publications of the Siemens Concern*, volume 14, 1935, page 16.

6. The Field in the Air Gap of Three-Phase Machines, W. Puts. *Institute of Technology*, (Berlin, Germany), 1933.

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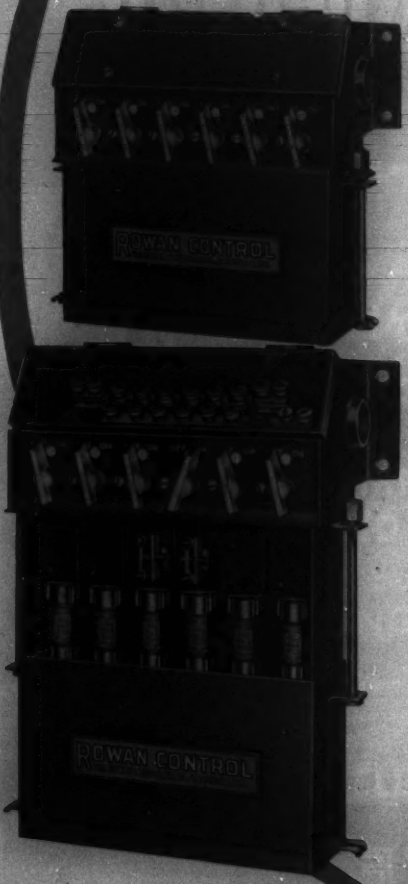


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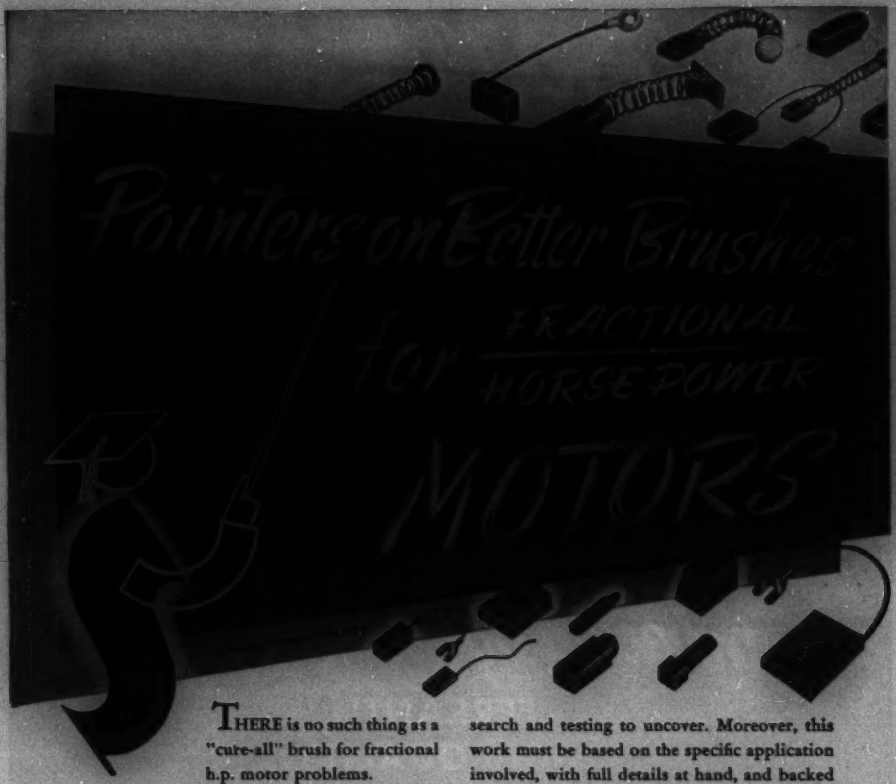


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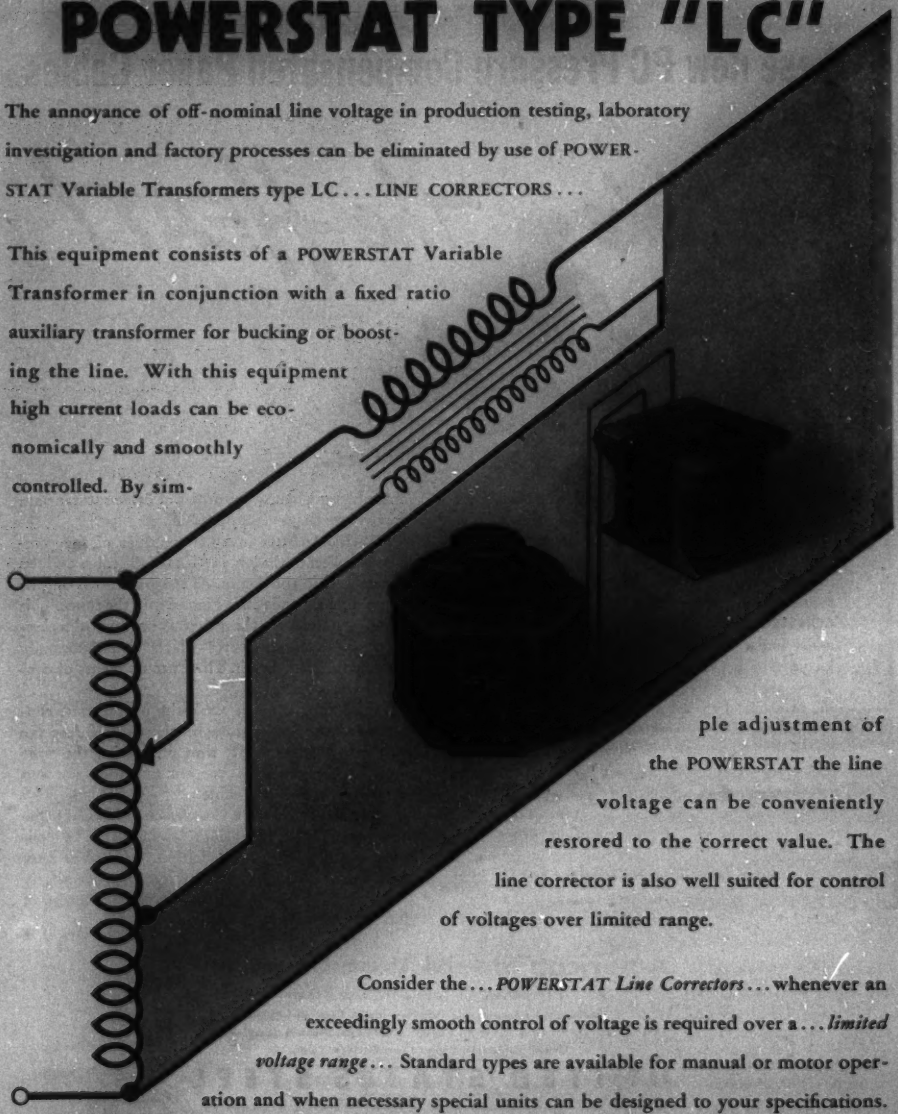

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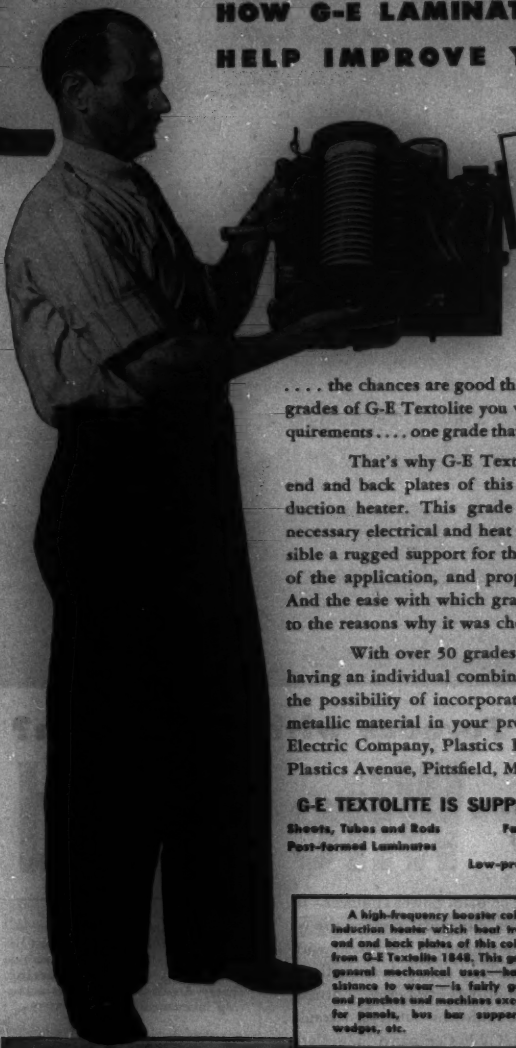

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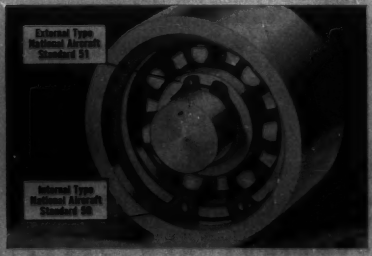


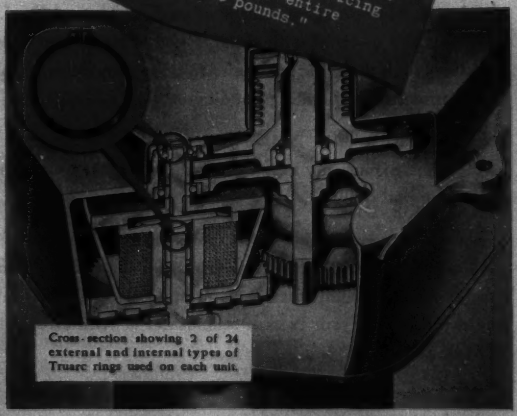

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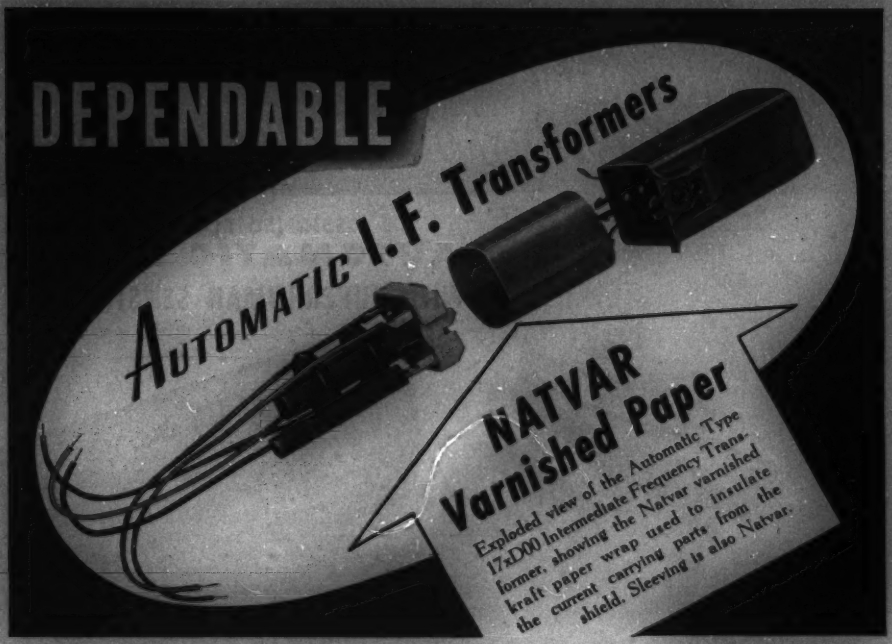

DEPENDABLE
AUTOMATIC I.F. Transformers
NATVAR
Varnished Paper
Exploded view of the Automatic Type 17xD00 Intermediate Frequency Transformer, showing the Natvar varnished kraft paper wrap used to insulate the current carrying parts from the shield. Sleeving is also Natvar.

Automatic Manufacturing Corporation, East Newark, N. J., wanted an insulating material with suitable power factor and resistance to moisture, high dielectric and uniformity, to provide *permanent* insulation under *any* operating conditions.

After exhaustive tests, Natvar varnished kraft paper was selected, and is used exclusively in the thousands of these transformers now being shipped daily.

If your requirements call for insulating materials of good physical and electrical performance characteristics — plus exceptional uniformity — plus prompt delivery — plus service, it will pay you to get in touch with your Natvar wholesaler or with us direct. Write, wire or phone.

Natvar

- Varnished cambric — straight cut and bias
- Varnished cable tape
- Varnished canvas
- Varnished duck
- Varnished cellulose acetate
- Varnished special rayon
- Varnished Fiberglas cloth
- Varnished papers
- Varnished tubings and sleeving
- Varnished identification markers
- Lacquered tubings and sleevings
- Extruded vinyl tubing
- Extruded vinyl identification markers

*Write for Catalog No. 20*

**THE NATIONAL VARNISHED PRODUCTS Corporation**

TELEPHONE RAHWAY 7-2171 — CABLE ADDRESS NATVAR: RAHWAY, N. J.

203 RANDOLPH AVENUE ★ WOODBRIDGE NEW JERSEY

For a good many years, transmission engineers thought largely in terms of non-ferrous materials for static wires. Yet at the same time these wires were installed on galvanized-steel towers with galvanized-steel fittings, the life of which was limited by the available zinc-coating weight.

Although this practice is still being followed in places, engineers are more and more swinging to bethanized steel strand for "overhead ground" or static wires. The advantages of steel for this purpose are numerous. In the first place, it is much less expensive than non-ferrous materials. With a steel line, too, you have fewer separation troubles—for steel is stronger and therefore sags less. And when it's a Bethlehem static wire, you get the long-term savings made possible by the bethanized coating.

Bethanizing is an exclusive Bethlehem process that applies a smooth, uniform, durable coating of zinc to every wire in the strand. The zinc, which is of high purity, is bonded directly to the steel; there is no intermediate layer of brittle zinc-iron alloy.

Bethanized coatings are available in A, B, and C weights, the choice depending upon corrosive conditions in your particular area. Even with the heaviest coating (C weight), bethanized strand is far more economical than any non-ferrous static wire —AND, with either a B or a C coating, its life expectancy may frequently exceed that of the towers and fittings.

For further details, write Bethlehem Steel Company, Bethlehem, Pa. We'll be glad to show you why a bethanized static line means economy . . protection . . long life.

★ BETHLEHEM STEEL ★

# ✓ CHECK THESE FEATURES...

## —features that emphasize the versatility of

## The DUMONT TYPE 247 OSCILLOGRAPH

### all these features *plus*...

exceptionally fine quality . . . well planned mechanical design . . . and completely dependable electrical performance . . . all of which make the DuMont Type 247 Cathode-Ray Oscillograph the logical choice for all applications that require a measuring instrument of fine accuracy.

★ *WRITE FOR DESCRIPTIVE LITERATURE*

**1 AUTOMATIC BEAM CONTROL FOR PHOTOGRAPHIC PURPOSES**

Permits high-contrast photographic recordings by holding the spot brightness at zero until the transient under study is initiated – then the spot is automatically raised to full brilliance.

**2 EXTENDED TIME BASE RANGE 0.5 to 50,000 C. P. S.**

A compensated circuit assures a linear sweep at all operating frequencies. The single sweep operates over a range corresponding to 0.5 to 10,000 c.p.s. The sweep is initiated by the controlling signal.

**3 VERTICAL AMPLIFIER RESPONSE UNIFORM–2 to 200,000 C. P. S.**

The response curve does not exhibit a positive slope above 1,000 c.p.s., thus assuring a linear phase-frequency relationship for the amplifier.

**4 HORIZONTAL AMPLIFIER MAY BE USED AS A D-C AMPLIFIER**

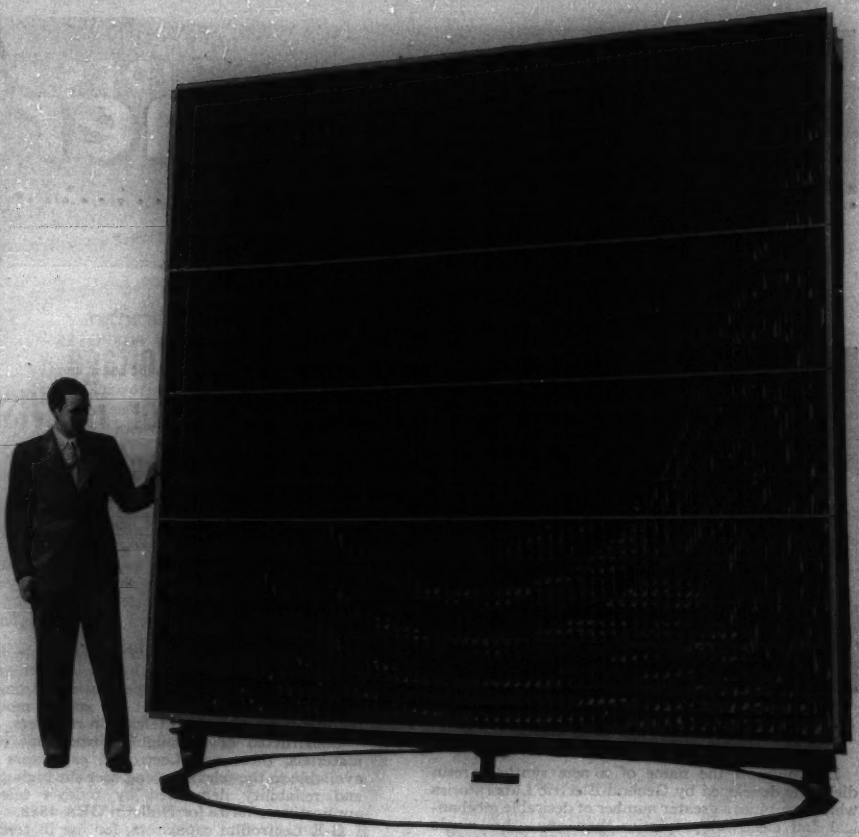
This amplifier is direct-coupled throughout, with the exception of an input capacitor which can be shorted out by operating a front-panel switch.

**5 3,000-VOLT ACCELERATING POTENTIAL PROVIDES BRIGHTER CRT PATTERN**

Sufficient brilliance for all but the highest writing rates without using special equipment.

**DUMONT** *Precision Electronics & Television*

ALLEN B. DUMONT LABORATORIES, INC. PASSAIC, NEW JERSEY • CABLE ADDRESS, ALBEEDU PASSAIC N. J. U. S. A.



# A "SEARCHLIGHT" TO FOCUS RADIO WAVES

In the new microwave radio relay system between New York and Boston, which Bell Laboratories are developing for the Bell System, giant lenses will shape and aim the wave energy as a searchlight aims a light beam.

This unique lens—an array of metal plates—receives divergent waves through a waveguide in the rear. As they pass between the metal plates their direction of motion is bent inward so that the energy travels out as a nearly parallel beam. At the next relay point a similar combination of lens and waveguide, working in reverse, funnels the energy back into a repeater for amplification and retransmission.

A product of fundamental research on waveguides, metallic lenses were first developed by the Laboratories during the war to produce precise radio beams.

This "searchlight" is a milestone in many months of inquiry through the realms of physics, mathematics and electronics. But how to focus waves is only one of many problems that Bell Telephone Laboratories are working on to speed microwave transmission. The goal of this and all Bell Laboratories research is the same—to keep on making American telephone service better and better.

BELL TELEPHONE LABORATORIES

EXPLORING AND INVENTING, DEVISING AND PERFECTING FOR CONTINUED IMPROVEMENTS AND ECONOMIES IN TELEPHONE SERVICE

ELECTRONICS

# Designer's

## LECTROFILM *at a glance*

Lectrofilm is the name of a new synthetic-resin dielectric developed by General Electric Laboratories which combines a greater number of desirable mechanical and electrical properties than any other single capacitor dielectric material. It is admirably suited for use in dry-type, high-voltage capacitors because it—

1. Withstands high and low ambient temperatures
2. Has low power factor and its power factor decreases as temperature rises
3. Has high dielectric strength and constant
4. Is chemically stable
5. Is strong and flexible
6. Has uniform characteristics
7. Is moisture resistant

## *New* High-Voltage CAPACITORS for TELEVISION Pulse Rectifiers

To smooth out the rectified high-voltage power supply in television and similar electronic applications, G.E. has developed a new line of small, light-weight, high-voltage capacitors. These new components are specially designed to meet the exacting restrictions in size and weight made necessary by the compact design of modern television receivers.

Currently available in two widely usable designs —flat cylindrical and long cylindrical—these Lectrofilm* units are equipped with prong-type terminals, designed to meet the special mounting requirements of modern television receivers.

Constructed of thoroughly tested and proved materials, these new Lectrofilm capacitors make available to the television engineer the high quality and reliability demanded by today's television applications. Write for Bulletin GEA-4558.

G-E Lectrofilm capacitors, for use in television pulse rectifiers, are now available in the ratings given in the following table. (Other ratings and designs will be available on request.)

### RATINGS AND DATA

Capacitance ratings: all sizes .0005 Mu-f. Capacitance tolerance: plus 35 per cent, minus 0 per cent.

| Peak Working Voltage | Cat. No. | Maximum R-F Current (Milliamperes) at frequencies of | | | Net Wt. in Oz. | Approx. Dimensions in Inches | |
|---|---|---|---|---|---|---|---|
| | | 20 Kc. | 100 Kc. | 300 Kc. | | Diameter | Length (Incl. terminals) |
| **FLAT CYLINDRICAL UNITS, with Terminals on Axis** | | | | | | | |
| 5000 | 29F201 | 15 | 50 | 150 | ½ | 1½ | 1½ |
| 7500 | 29F200 | 20 | 75 | 200 | ¾ | 1½ | 1¾ |
| 10,000 | 29F194 | 25 | 100 | 300 | 1½ | 2½ | 1¾ |
| 16,000 | 29F206 | 30 | 120 | 380 | 4½ | 3½ | 3½ |
| **LONG CYLINDRICAL UNITS, with Terminals on Axis** | | | | | | | |
| 5000 | 29F203 | 10 | 40 | 100 | ¾ | | 2½ |
| 7500 | 29F204 | 10 | 40 | 100 | 1 | | 3 |
| 10,000 | 29F202 | 10 | 40 | 100 | 1½ | | 4 |
| 16,000 | 29F205 | 15 | 80 | 125 | 3 | 1½ | 8 |

* General Electric's new synthetic-resin dielectric

# Digest

## TIMELY HIGHLIGHTS ON G-E COMPONENTS

## MORE MAGNET *in less space*

G-E alnico magnets are the answer to many a tough problem in design, where coercive force must be large, and the magnet small.

They are formed by the cast as well as the sintered process which makes possible rapid, large-scale, close-tolerance manufacture of both complex and simple shapes. Compact, with uniform flux distribution and great stability, these mighty midgets facilitate the design of small devices of high precision. Write for Bulletin GEA-3682A.

## EVER NEED *a non-linear resistance?*

Frequently, electronic designers need a non-linear resistance to protect against voltage surges, to stabilize power voltages or to control voltage-selective circuits. In Thyrite*, General Electric's silicon-carbide resistance material, current varies as a power of the applied voltage. That is, I varies as $E^4$.

For example, with a Thyrite resistor whose exponent is 4, doubling the voltage multiplies the current by $2^4$ or 16, whereas doubling the voltage applied to a wire-wound resistor merely doubles the current.

Thyrite resistors are supplied in discs or rods, in diameters from 0.25 in. to 6.0 in. Write for Bulletin GEA-4138A.

* Trade-mark Reg. U. S. Pat. Off.

## TIGHT, FAST JOINTS *begin with the soldering iron*

With the new line of G-E soldering irons, operators can solder just as fast as the nature of the job permits. Tips stay hot during constant use. The Calrod heating element close to the tip gives a short, low-loss heat path to the work.

Sturdy construction prevents work interruptions due to iron failure. Repairs are infrequent, even under severe conditions. Available in five sizes and types, from 75 to 300 watts, 115 volt or 230 volt. Write for Bulletin GEA-4519.

## A LOT OF INSTRUMENT *in a little space*

These thin, internal-pivot panel instruments have high torque, good damping, and a lightweight moving element that withstands vibration. They respond rapidly and accurately. They give you more instrument in less space, because the internal-pivot construction makes the entire element assembly 20 per cent thinner than most outside-pivoted types. Ask for details of the Type DW voltmeter or ammeter—milli, micro, or radio frequency. Bulletin GEA-4064.

## REMOTE CONTROLS *that stay in step*

G-E selsyns *stay* synchronized; that is why they are so widely used for remote control and indication applications with single and multiple receivers.

Three sizes of high-accuracy selsyns give operation to within plus or minus 1 degree. Where plus or minus 5 degrees is close enough, use lower cost general-purpose selsyns.

Accuracy values are for 60 cycle, 110 volt operation. Write for Bulletin GEA-2176A.

**General Electric Company, Sec. 642-11**
**Apparatus Dept., Schenectady 5, N. Y.**

**Please send me**

- ..... GEA-4538 (Lectrofilm capacitors)
- ..... GEA-3682A (Sintered alnico magnets)
- ..... GEA-4064 (Panel instruments)
- ..... GEA-4138A (Thyrite)
- ..... GEA-4519 (Soldering irons)
- ..... GEA-2176A (Selsyns)

NOTE: more data available in Swoop' Pix for Product Designers

Name .....

Company .....

Address .....

City ..... State .....

PERMANENT MAGNETS MAY DO IT BETTER

FLUXMETER CLOSED CIRCUIT TEST

Testing magnet in an assembly similar to the finished unit.

## ACCURATE TESTING OF PERMANENT MAGNETS

Because the permanent magnet is one of the most vital parts of the instrument or apparatus in which it is used, testing methods of the mechanical and magnetic properties must be comparable to the actual working condition of the magnet.

Our testing department is equipped with every facility to insure accurate mechanical inspection. Every magnet is tested to magnetic specifications, so that they will function properly in their final assembly . . . reducing customers' inspections.

Fluxmeters, ballistic galvanometers, test fixtures and all associated precision apparatus used in testing and inspecting are constantly checked to maintain absolute uniformity.

Over 24,000 applications of permanent magnets have been developed by *Indiana Steel Products Company*, specialists in permanent magnets for over 35 years. You are invited to consult with our engineers. For data on magnet applications, write for new "Permanent Magnet Manual."

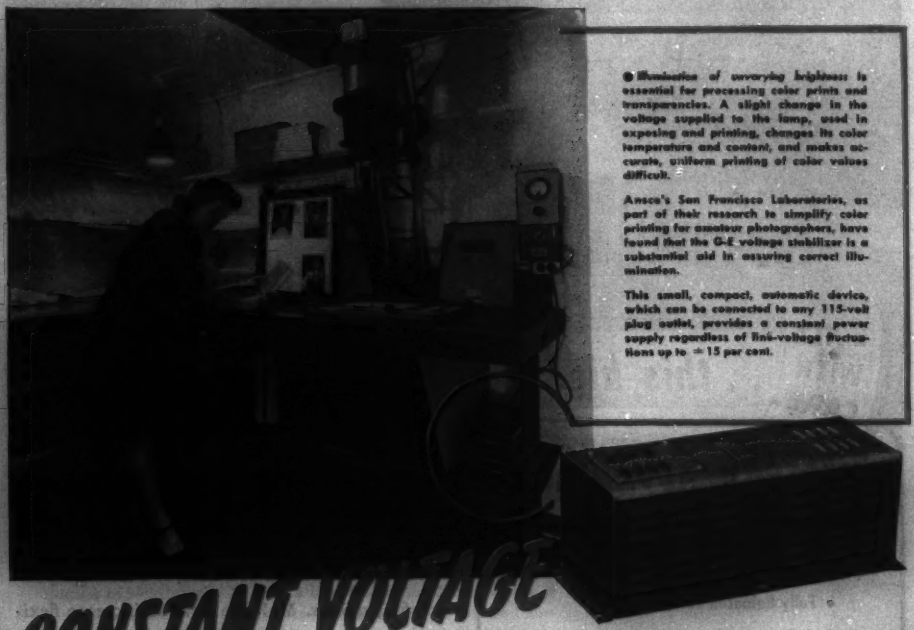
***Producers of* "PACKAGED ENERGY"**

THE INDIANA STEEL PRODUCTS COMPANY

6 NORTH MICHIGAN AVENUE, CHICAGO 2, ILLINOIS

SPECIALISTS IN PERMANENT MAGNETS SINCE 1910

# ANSCO Gets Better Color Prints with G-E Voltage Stabilizer



● Illumination of unvarying brightness is essential for processing color prints and transparencies. A slight change in the voltage supplied to the lamp, used in exposing and printing, changes its color temperature and content, and makes accurate, uniform printing of color values difficult.

Ansco's San Francisco Laboratories, as part of their research to simplify color printing for amateur photographers, have found that the G-E voltage stabilizer is a substantial aid in assuring correct illumination.

This small, compact, automatic device, which can be connected to any 115-volt plug outlet, provides a constant power supply regardless of line-voltage fluctuations up to ± 15 per cent.

## CONSTANT VOLTAGE

### may add new accuracy to your precision jobs, too

● On almost every precision job where electricity is used, a closely held voltage supply adds speed or accuracy, or decreases rejects. In addition, it protects delicate instruments, tools and electronic tubes from sudden overvoltages, and increases the reliability and life of such equipment.

If you are a user or manufacturer of such apparatus as radio transmitters, testing equipment, X-ray machines, other electronic devices, motion-picture projectors, and precision photographic equipment, it will pay you to investigate the benefits of G-E voltage stabilizers. They can be used as an accessory to present equipment or built into new, redesigned products to add salability.

These small, compact units are available in ratings from 50 to 5000 va. On circuits where the voltage may vary from 95 to 130 or 190 to 260 volts, they automatically provide a constant 115- or 230-volt output. Because they have no moving parts, the need for maintenance is practically nonexistent. Ask for Bulletin GEA-3634A for complete information. *General Electric Company, Schenectady 5, N. Y.*

GENERAL ELECTRIC

# AMERTRAN QUALITY

*is maintained by*

## CARE

*. . . in hundreds of details*

BUILT WITH CARE

## . . this high current winding is typical

### AMERTRAN ADVANTAGES:

- High turn-to-turn insulation
- Linear surge-voltage characteristics
- Fully balanced coil design
- Coils vacuum impregnated
- Rigid core construction
- Optimum impedance
- "Tailored" tanks
- Electrically brazed connections
- Rust resistant external parts

A SPECIAL AmerTran procedure is used to position multi-conductor windings. In this case 39 conductors (totalling ½" thick by 4¼" wide) are wound at one time, fed through non-chafing guides. Multiple strands increase flexibility, prevent permanent distortion from surges, and reduce eddy losses in the coils. Transpositions further neutralize disturbing currents.

Rigid blocking and neat taping contribute to a firm, symmetrical winding of uniform stress and high electrical efficiency.

Equal care in all other AmerTran manufacturing operations has helped maintain AmerTran leadership in transformer practice—for 45 years.

AMERTRAN

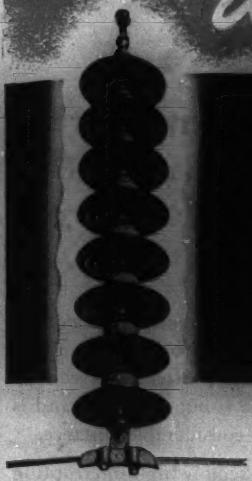
MANUFACTURING SINCE 1901 AT NEWARK N. J.

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

**AMERICAN TRANSFORMER COMPANY**

178 Emmet Street • Newark 5, New Jersey

# WHAT MAKES A "LIGHTNING PROOF" LINE *Lightning Proof?*



**A case in point: This 26-mile line was built in 1917 at 66 Kv., and raised to 132 Kv. in 1922. So far, in spite of good inspection, not one O-B insulator has come out of service due to any inherent defect. This is a highly significant fact to the engineer contemplating lightning-proof construction, and needing absolutely reliable insulation.**

To start with, you can do it--you can build a transmission line to survive storm periods and maintain a pre-determined degree of reliability... In such a line, one of the basic factors is the maintenance of a constant insulation level. A few bad suspension units in a mile of line might not show up in ordinary operation, but they would definitely degrade lightning performance... By constant vigilance, *any* insulator can be kept at the high performance level necessitated by lightning-proof construction, but by simply installing O-B suspension insulators in the first place you have the maximum assurance of reliable performance without the need for continual checking... This is a fact: O-B suspension insulators out-number all other makes, and have served longer, by official record. In terms of both years and number, they have proved themselves to have the lowest depreciation rate. This is something you *need* in modern lightning-proof lines--something you can get very easily and very surely merely by specifying O-B suspension insulators.

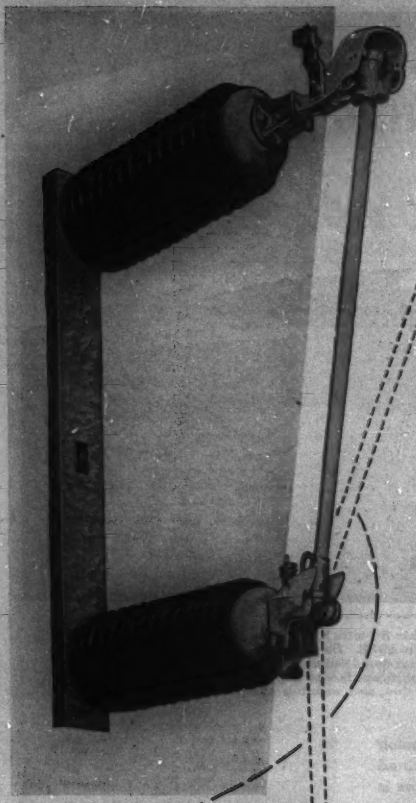
**Ohio Brass**

MANSFIELD, OHIO

CANADIAN OHIO BRASS CO., LTD., NIAGARA FALLS, ONT.

HEADQUARTERS FOR PORCELAIN INSULATION

5948-H



1

After clearing a fault the fuse tube moves to the open position removing it from the circuit and providing a clear "semafor" signal that the fuse has been blown.

2

In the case of 69 kv fuse—following operation—the fuse tube is moved with a switch stick from the restrained position to the full open position for removal from the mounting.

3

Lifting out the blown fuse with a hook stick permits refilling conveniently and easily, with the S&C Type SSM Refill Unit.

The short circuit interrupting rating of the unit illustrated is 4000 r.m.s. amperes at 66,000 volts. Correspondingly high interrupting ratings at other voltages.

## This is the S&C Type "HSO"

## ...the most modern power fuse.....with "drop out" feature advantages.....

The S&C Type HSO protective unit combines high interrupting capacity with the added protection afforded by "drop out" action after fault current interruption. A blown fuse is out of circuit, and is readily distinguishable at considerable distance.

In the HSO Power Fuse assembly high interrupting capacity results from the proper design of a boric acid arc extinguisher unit. The "drop out" mechanism is sleet protected, and, in the higher voltage ratings, is also equipped with a snubbing device which prevents any mechanical damage which might occur in a full swing to open position.

A number of the larger power companies have already applied the S&C Type HSO Power Fuse extensively with marked success and satisfaction. Let us send YOU full information . . . NOW!

**Schweitzer & Conrad, Inc.**

4427 RAVENSWOOD AVE., CHICAGO 40, U. S. A.

*Represented in Principal Cities (Consult Telephone Directory)*
*In Canada by Powerlite Devices, Ltd., Toronto, Ont.*

# *Every* Coil Replacement *deserves expert care...*

Above is view of a 3750-KVA, 3600-V, 1200-RPM generator being operated by the customer, using National Electric uniformly good coils and insulating supplies.

**Almost every electric winding failure is a story of progressive deterioration. Some seemingly minor insulation detail is weakened by heat, aging or operating service conditions. Deterioration of that "minor" detail continues; the coil fails, and that means failure of the entire machine . . . expense . . . loss of service.**

**Quite possibly, if that one "minor" detail had not faltered, life of the machine between outages would have been increased by 10%, 50%, 100% . . . or more.**

**And so, was it *really* a minor failure?**

**Users know that National replacement coils are good. More than that, they know that they are uniformly good. They know the economies of *uniformly* long-lived coils: fewer coil purchases—fewer coil installations—fewer interruptions to operation.**

**A case in point—The generator shown in the photograph at the left is now operating with 96 good—uniformly good—National replacement coils. When it failed we at National Electric Coil were advised to supply a complete set of coils and winding supplies. We promised delivery within 35 days, maximum, f.o.b. Columbus. Actual deliveries were made at the customer's plant:**

**First shipment of 25 coils plus supplies . . . . . 22 days**
**Second shipment of 24 coils . . . 23 days**
**Final shipment of 47 coils . . . . 27 days**

**The coils were there ahead of time. Of at least equal importance is the fact that the attention we always give to the many "minor" details of coil shape, insulation and coil accessories, along with up-to-the-minute construction, insures that every one of the 96 coils can be relied upon for maximum length of life.**

**If you want the long-life coil uniformity which seems to us to be essential, use National replacement coils.**

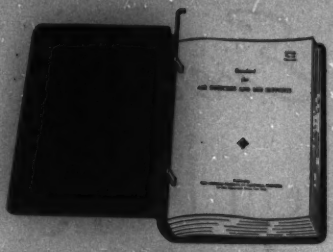
## NATIONAL ELECTRIC COIL COMPANY

COLUMBUS 16, OHIO, U. S. A.

ELECTRICAL ENGINEERS, DESIGNERS AND MANUFACTURERS EXPERT COIL SPECIALISTS

REDESIGNING AND REPAIRING OF ROTATING ELECTRICAL MACHINES

THE Standards of the American Institute of Electrical Engineers now comprise fifty sections on electric machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



The Standards available are listed below, together with prices. A discount of 50%, on single copies only, is allowed to Institute members (except as noted). Such discount is not applicable on extra copies unless ordered for other members. A binder (illustrated above) for Standards is available with durable, stiff covers, resembling leather, lettered in gold. Price $1.75 net per binder. Two binders are necessary to hold a complete set of Standards, Reports and Test Codes.

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| | 1B | Report on Guiding Principles for Specification of Service Conditions (May 1944) | .10 |
| | 3 | Guiding Principles for Selection of Reference Values for Electrical Standards (Oct. 1943) | .30 |
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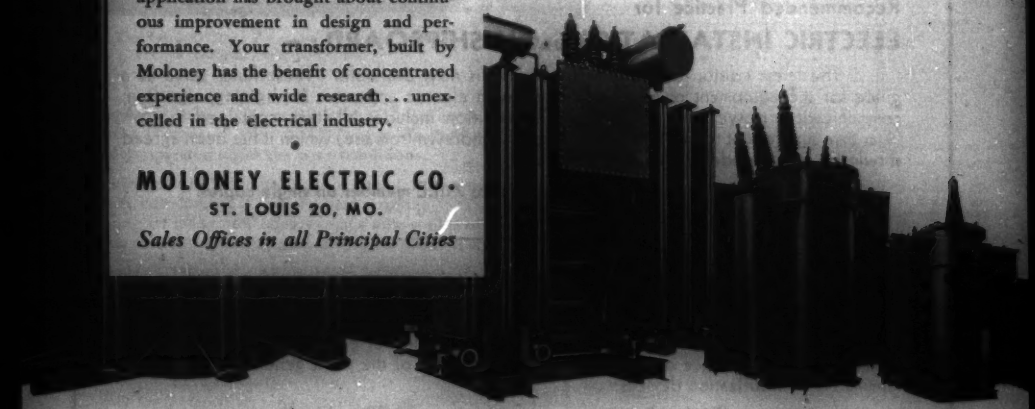

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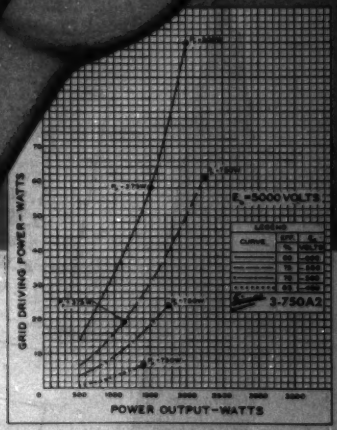


*Typical of the outstanding performance of this new triode is its high power gain. With 5000 volts on the plate, the new Eimac 3-750A2 will deliver 2000 watts output with only 50 watts driving power, at a plate efficiency of 75%. (See above chart.)*

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| | | |
|---|---|---|
| Filament: Thoriated tungsten | | |
| Voltage | 7.5 | volts |
| Current | 21.0 | amperes |
| Amplification Factor (Average) | 15 | |
| Direct Interelectrode Capacitances (Average) | | |
| Grid-Plate | 5.8 | uuf |
| Grid-Filament | 8.5 | uuf |
| Plate-Filament | 1.2 | uuf |
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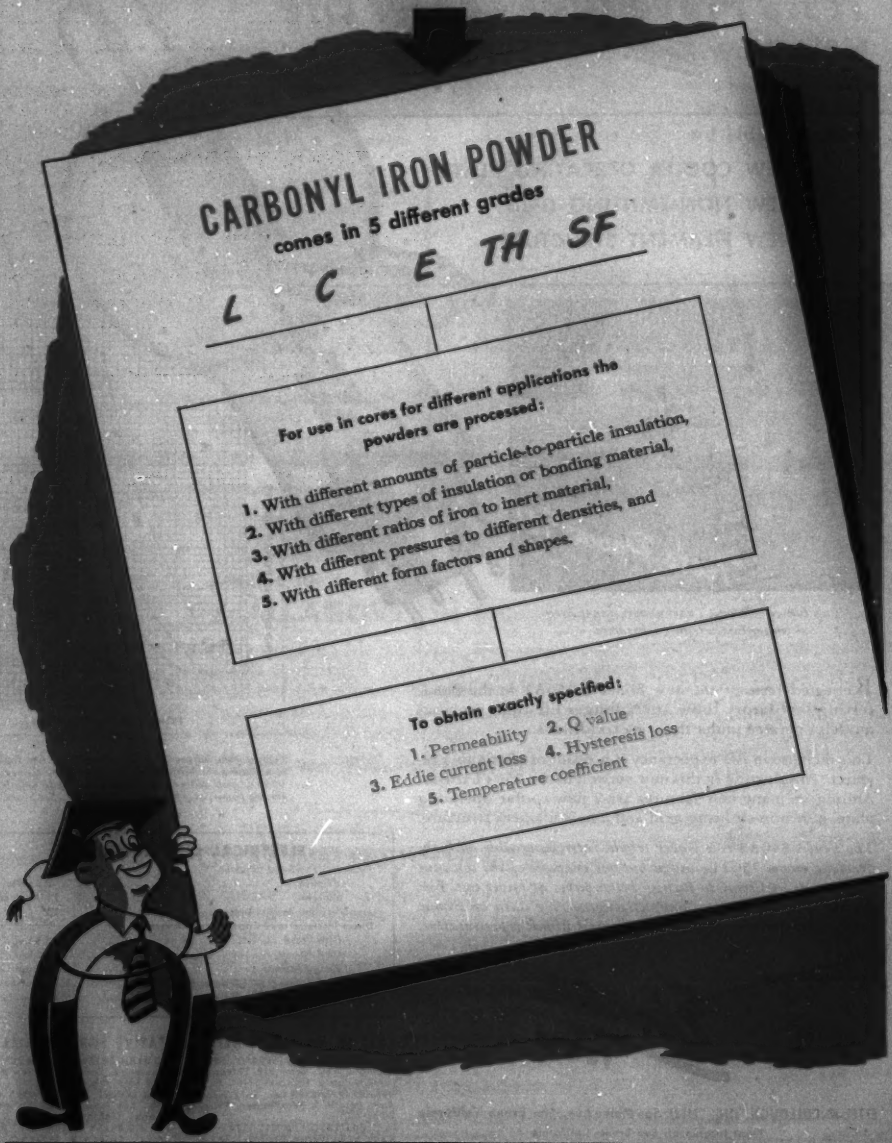
# Data for all designers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| WEIGHT Exclusive of Housing, Mounting, etc. | 1.5 ounces | 1.0 ounces | Saves 33% of Weight |
| WIRE-LENGTH | 25 feet | 11 feet | Saves 60% of Wire |
| INDUCTANCE | 117 Micro-Henries | 169 Micro-Henries | Increases Inductance 40% |
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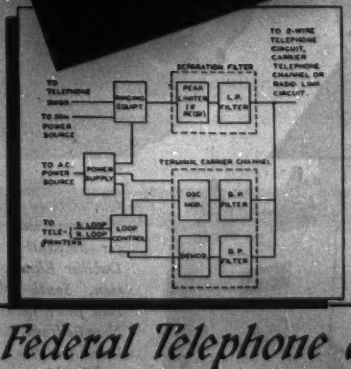
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*Our engineers will be glad to cooperate with you. Send for our catalog. Cornell-Dubilier Electric Corporation. South Plainfield New Jersey. Other plants in New Bedford, Brookline, Worcester, Massachusetts and Providence, R. I.*

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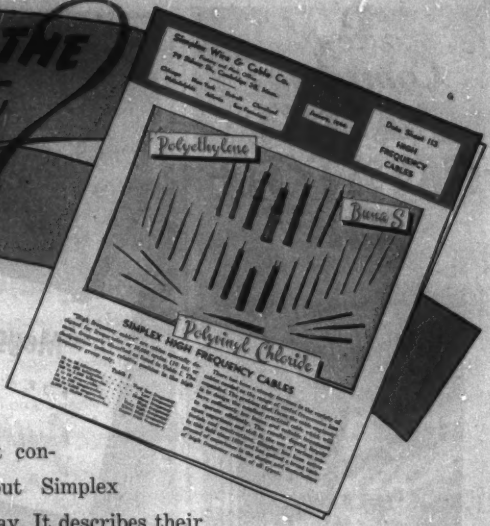


Reproduced above is the front page from the new Simplex Data Sheet covering High Frequency Coaxial Cables. This new Data Sheet contains a wealth of information about Simplex Coaxial Cables which are available today. It describes their construction, physical size, the recommended operating frequency, the impedance in ohms, the capacitance per foot and similar information.

If you would like a copy of Data Sheet 113, we would be happy to have you drop us a line and we will send you one without any further obligation.

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*Write for Bulletin 206*

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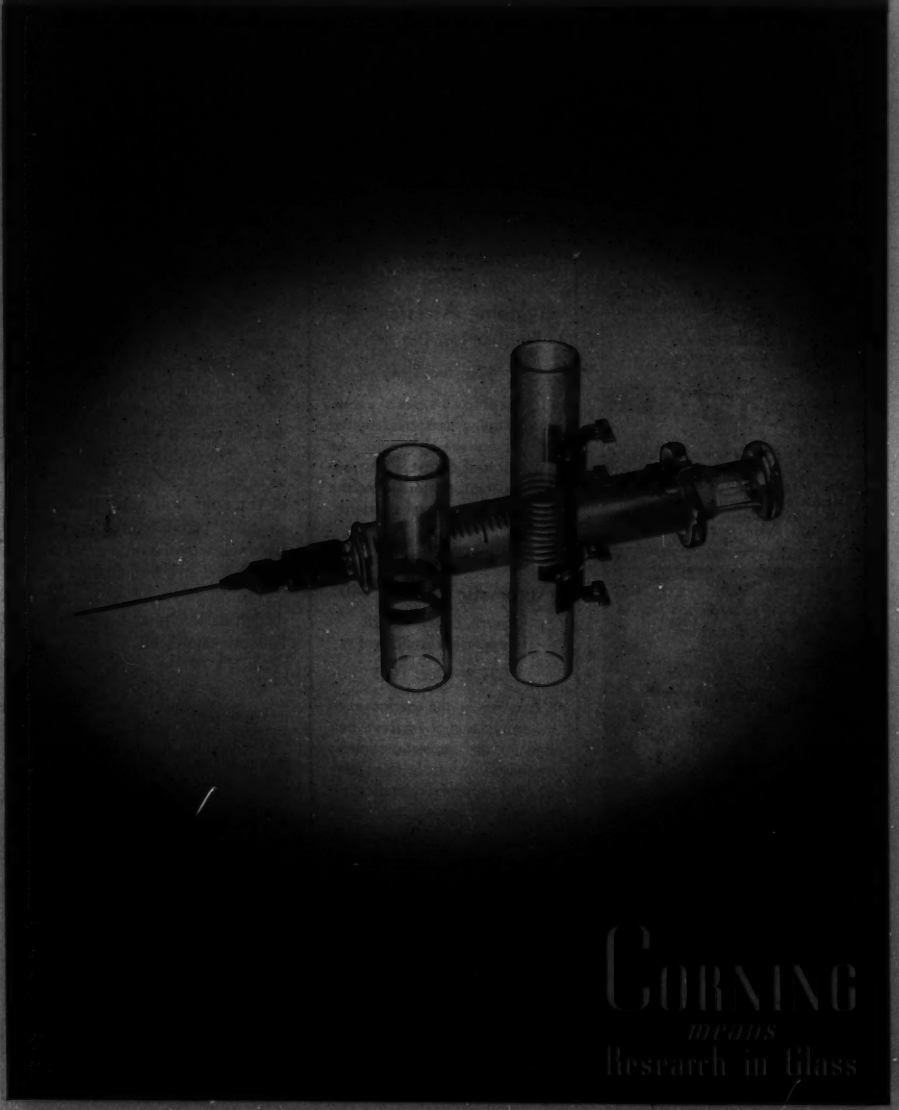

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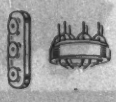

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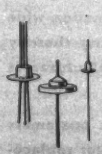

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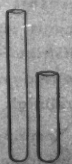

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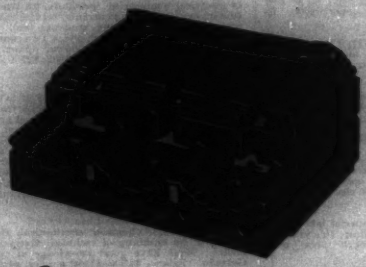

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**All replies should be addressed to the key numbers indicated and mailed to the New York Office.**

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## WANTED

Copies of the January, February (1944) and November (1945) issues of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 W. 39th St., New York City (18), printing your name and address upon the enclosed wrapper. Twenty-five cents plus postage, will be paid for each copy returned.

## Positions Available

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## CORRECTION

"Recommended Practice for Electric Installations on Shipboard" AIEE No. 45

ERRATA—Standard 45, Pages 30 and 31
Sections 18, 65, 67, 69, 81, 83 and 85
In "Third" change "0.136 in." to "0.115 in."

*Errata sheets for insertion in the 1945 edition can be obtained by writing to*
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS - 33 W. 39th St., New York 18, N. Y.

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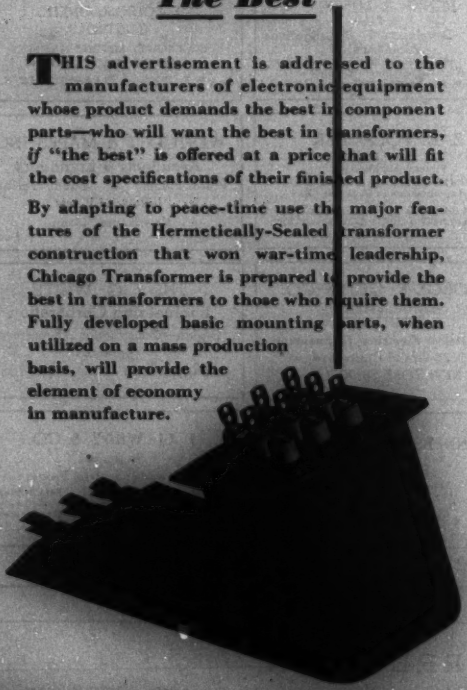

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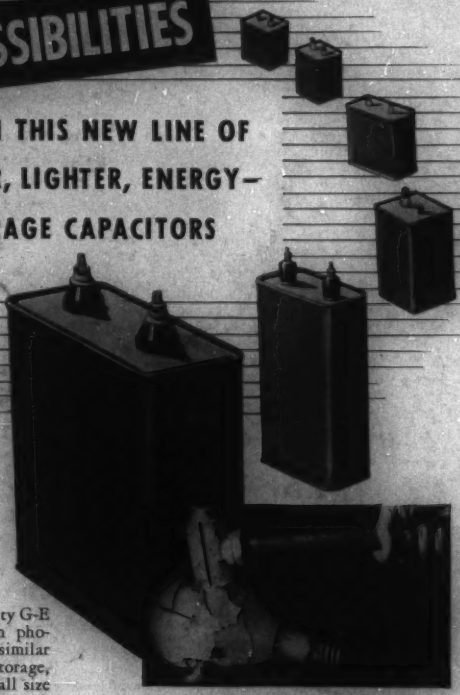

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| 3350 | 17.8 | 100 | 25F912 | A | 7 | 8 1/4 | 1 | 7.8 |
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